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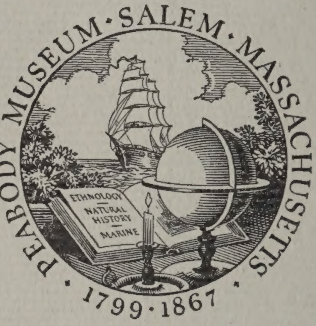

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AUTHOR'S PREFACE TO THE SECOND EDITION.

It is a source of sincere gratification to the writer to find that a Second Edition of this book has been called for within a few months of its first appearance, proving that the conviction which led to its production was not ill-founded — viz., that ships' officers and those generally associated with shipping desire a more complete and reliable knowledge of their ships.

Shipbuilders, ships' officers, and the press have testified to the need and to the usefulness of this work, and it only remains for the author to express his thanks for the generous way in which the book has been received.

October, 1896.

EDITOR'S PREFATORY NOTE.

THIS SERIES has been designed to meet the growing desire on the part of Officers in the Mercantile Marine for a MORE SCIENTIFIC INSIGHT into the principles of their profession, and the sciences upon which the Art of Navigation is founded. The treatises are, for the most part, WRITTEN BY SAILORS FOR SAILORS; and, where this is not the case, by authors who have special knowledge of the subjects dealt with and their application to the Sailor's life. The treatment will be thoroughly scientific, yet as free as possible from abstruse technicalities, and the style such as will render it easy for the young sailor to gain a knowledge of the elements of his profession by private reading and without difficulty.

E. B.

LONDON, *March*, *1896.*

AUTHOR'S PREFACE.

EXPERIENCE is a wonderful teacher, though often a very slow one. In the course of time, it will instil into a seaman's mind a considerable knowledge of the capabilities and behaviour of his vessel under varying circumstances—her strength, her carrying capacity, her stability, or, in other words, her sea qualities.

This mode of obtaining knowledge is, however, far too costly for the intelligent seaman of to-day. He knows that many a good ship, and what is worse, many precious lives have been lost before it has been acquired, and all through pure—though it would be unjust to say, wilful—ignorance.

As regards the subject of stability, it has been said that it is useless to provide a captain with curves of stability, for he does not understand them, and if he did, they are of little use, all he requires being a statement of certain conditions of loading, beyond which he must not go, or his vessel will be unsafe. This is all very good in its way, but why does the captain not understand curves of stability, or, more broadly speaking, the subject of stability? Is not the answer this, that very little indeed has been done to provide the means of his obtaining such important information? Besides, if the curves are of little use, and a statement of conditions to ensure safety is sufficient, some credit must be given to the intelligence of the ship's officer of to-day. Let him not be put down as a machine to steer a ship, incapable of comprehending what may be reduced to a subject of comparative simplicity. On the other hand, let not the mistake be made that lengthy experience in navigating ships necessarily means capability to so load any ship as to produce seaworthiness. The ignorance often displayed in loading and ballasting vessels, and the loss resulting therefrom, prove that such is not the case.

It is evidently often imagined that able, valuable, and instructive papers and lectures on vital subjects relating to ships are only for, and interesting to, naval architects and experts, and that to ship's officers they are either unnecessary or else they have no interest in this means of instruction. A more foolish and unjust conclusion could scarcely be arrived at. If the stability of a vessel depends so much upon the loading, and officers superintend the loading of their own vessels, at anyrate in foreign ports, if not always at home, the importance of an intelligent knowledge of the subject must be evident.

Moreover, is it not a fact that with this knowledge the ship's officer would be able to supply a great amount of valuable data to the shipbuilder and naval architect concerning the behaviour and capabilities of his vessel under every condition of weather and loading, which could not fail to be of immense value in the designing of future ships? By this means, the designer, who, as a rule, sees little of the ship he designs after a few hours' trial trip, generally under the most favourable circumstances, would then be the better able to produce a vessel more perfectly adapted to her requirements.

That such is the case is proved by the fact that some leading shipbuilding firms do everything in their power to encourage ship captains to give all the information they possibly can regarding the behaviour and performance of the vessels which they have built.

The best method of supplying this kind of instruction to seamen is believed to be by means of lectures thoroughly illustrated by diagrams and experiments.

During the past few years the writer has given in the Government Navigation School, Leith, N.B., courses of lectures, specially designed for the instruction of seamen. The eagerness and enthusiasm displayed to obtain such information made it manifest that seamen are fully awake to its importance, and appreciate and understand its value. The able discussion which often followed these lectures, and the important points and features brought out in connection with personal experience, furthermore proved that seamen want no rule-of-thumb methods for guidance, but that a thorough grasp of the principles of the subject is required. This, together with the repeated requests which have been made to publish these lectures, has tempted the writer to do so in the form of this book. The old-fashioned method of "beginning at the beginning" of the subject has been adopted as the only trustworthy way of dealing with it; and while endeavouring to cover as much ground as possible, the aim has been to condense the matter as far as compatible with clearness, to present it in language easy enough to be understood by every seaman, and stripped of laborious mathematical formulæ, and at a cost which will place it within reach of seamen of limited means.

It is felt that no apology is necessary in presenting this book, for while the excellent work of Sir E. J. Reed and also that of Sir W. H. White are admirably adapted to the requirements of the naval architect and the shipbuilder, it is believed that no special attempt has been made to supply the need of seamen generally.

It is further hoped that the Chapters on Construction, Tonnage, and Freeboard, while interesting and important subjects to seamen, will make the book acceptable to the shipowner, ship superintendent, ship draughtsman, and to those generally interested in shipping.

The Author's sincerest thanks are due to Messrs. W. Denny & Brothers, Dumbarton; to Messrs. J. L. Thompson & Sons, Ltd., Sunderland; and to Messrs. Ramage & Ferguson, Ltd., Leith, for permission to use curves of stability of vessels built by them; and also to J. Bolam, Esq., Head Master of the Government Navigation School, Leith, for the kindly sympathy and interest which he has manifested in the preparation of the book.

Suggestions and communications—especially from Ships Officers and others desirous of promoting this branch of nautical instruction—will be gladly welcomed and acknowledged in future editions of this work, should these be called for.

LEITH, *March*, 1896.

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KNOW YOUR OWN SHIP.

CHAPTER I.

DISPLACEMENT AND DEADWEIGHT.

CONTENTS.—Displacement—Displacement Curves—Deadweight—Deadweight Scale—"Tons per Inch Immersion"—Examples of Practical Application of "Tons per Inch Immersion" Curve—Coefficients of Displacement.

Terms.—"Displacement," "Deadweight," and "Tonnage" are terms often heard and used by those associated with ships and shipping in some form or other, but not always definitely understood. Their simplicity, however, renders them easy of explanation, and we shall, at the outset, devote our attention briefly to the two former—Displacement and Deadweight. The last—Tonnage—being a subject of larger dimensions, though simple in its character—will be reserved for a later Chapter.

Displacement.—Any object floating in water displaces or dislodges a volume of water, and the weight of the displaced water is equal to the weight of the floating object. The prefix "dis" in the word "displacement" means "away from." Thus, displacement reveals its own meaning—viz., that which is placed out of its usual condition.

Displacement, in the technical sense in which it is applied to ships, or any other floating bodies, refers to the displacing of the water by the total or partial immersion of any object placed in it. The volume of water displaced may be measured in cubic feet or in tons, and the weight of water displaced is called the *Displacement.*

This fact may be simply illustrated by supposing a tank to be filled to the brim with water, and when in this condition let a box-shaped ship—3 feet long, 2 feet broad, and 2 feet deep—be placed in it, sinking to a depth of 1 foot. It is evident that if the tank were full before the ship was placed in it, some of the water must have overflowed (Fig. 1).

Let a receiver be placed below the tank, with a reservoir 3 feet long, 2 feet broad, and 1 foot deep (exactly the same dimensions as the immersed part of the ship) attached to the bottom. It would be found that immediately the overflow had ceased, the reservoir would be just filled as shown by the dotted lines. This proves that the volume of water displaced is exactly equal to the volume of the immersed portion of the ship. Moreover, if the ship could be placed in one balance, and the displaced water in another, they would be found to exactly equal each other in weight. But supposing the ship were too large for any process of weighing to be adopted, the displacement could be ascertained by a very simple calculation.

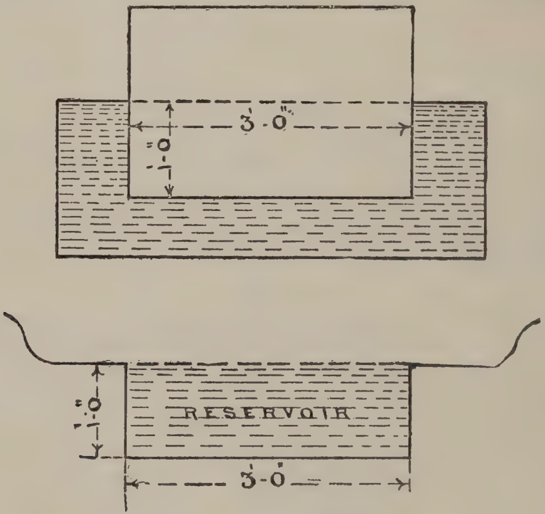


Fig. 1.—Displacement.

A cubic foot of sea water weighs 64 lbs., and 35 cubic feet of sea water weigh 1 ton. Multiply together the length, breadth, and draught of the ship, and we get cubic feet; 3 × 2 × 1 = 6 cubic feet. Therefore, since 1 cubic foot weighs 64 lbs., 6 cubic feet will equal 6 × 64 = 384 lbs. displacement, and this, while being the weight of water in the reservoir, is also the total weight of the ship in its present condition.

Again, supposing an unknown weight be placed in the ship increasing the draught to 1 foot 6 inches, or 1·5 feet, then 3 × 2 × 1·5 = 9 cubic feet, 9 × 64 = 576 lbs. total displacement.

The displacement, when the ship was empty, was 384 lbs., therefore the weight added is 576 − 384 = 192 lbs.

In dealing with floating objects not box-shaped, such as real ships, although the same method of computing the displacement cannot be adopted owing to the difference in form, yet the principle, that the weight of water displaced equals the total weight of the ship, remains the same. This important fact, as is evident, proves of immense value to shipbuilder and shipowner alike, for had the weight of a ship to be found by estimating the weight of every item in it—hull, engines, boilers, masts, &c. —separately, and adding them together, it will be seen how

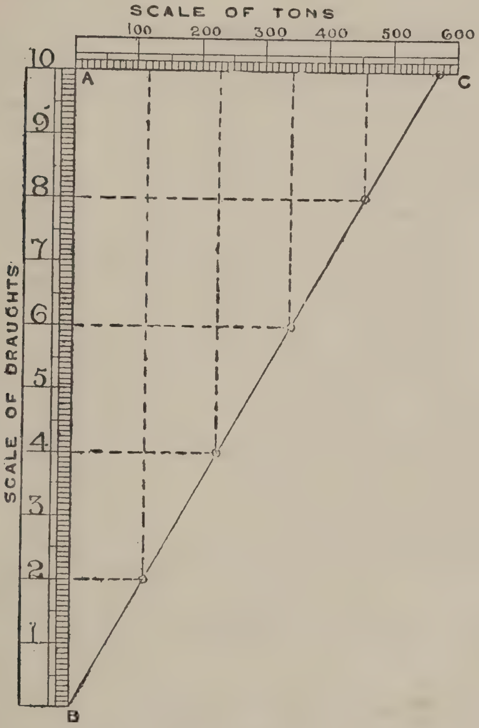


FIG. 2.—DISPLACEMENT CURVE.

laborious the process, and how inaccurate the result, might possibly be.

The length, breadth, and draught of a ship cannot be multiplied together for displacement, but, by the application of a simple method known as Simpson's rules, the volume of the immersed portion of the ship can be ascertained, which, if considered as water, and divided by 35, will give the displacement in tons.

To make a separate calculation whenever the displacement is required at any particular draught would entail considerable labour and inconvenience. This is avoided by using what is termed a *Displacement Curve*, by means of which, in a moment, the displacement can be read off at any draught. It is constructed in the following manner (Fig. 2).

Draw the vertical line AB, and upon it construct a scale at, say ½ inch = 1 foot, indicating the draughts up to the load line, exactly as read upon the stem or stern of a vessel, inserting in each foot space twelve equal divisions for inches. From the top of the line AB draw the horizontal line AC. Divide this line into ½-inch spaces, each one representing 100 tons of displacement. Sub-divide the spaces again into tenths, each of which will, therefore, represent 10 tons. Supposing our vessel be of box form, 100 feet long, 20 feet broad, and 10 feet draught, then by calculating the displacement at a series of draughts, say 2, 4, 6, 8, and 10 feet respectively, we are in a position to find a number of points by means of which the displacement curve is constructed.

The displacement at—

2 feet draught = 100 × 20 × 2 = 4,000 cubic feet

$$\frac{4{,}000}{35} = 114{\cdot}2 \text{ tons.}$$

4 feet draught = 100 × 20 × 4 = 8,000 cubic feet

$$\frac{8{,}000}{35} = 228{\cdot}5 \text{ tons.}$$

6 feet draught = 100 × 20 × 6 = 12,000 cubic feet

$$\frac{12{,}000}{35} = 342{\cdot}8 \text{ tons}$$

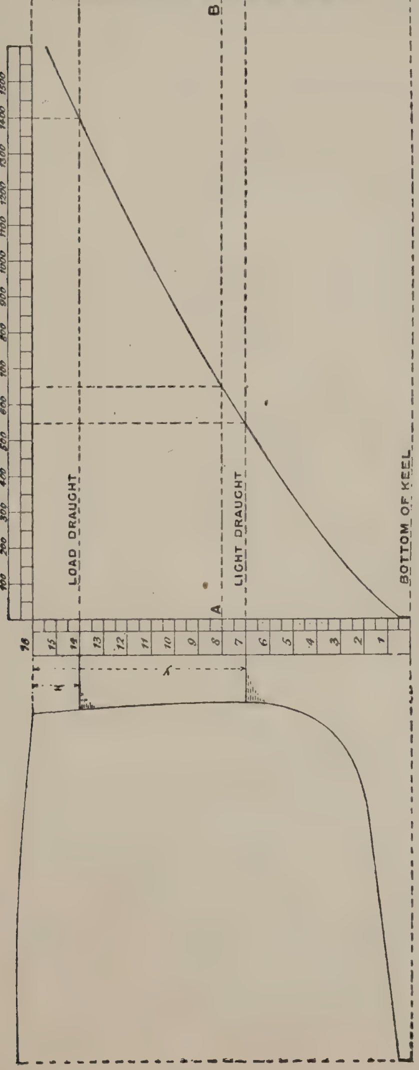
8 feet draught = 100 × 20 × 8 = 16,000 cubic feet

$$\frac{16{,}000}{35} = 457{\cdot}1 \text{ tons.}$$

10 feet draught = 100 × 20 × 10 = 20,000 cubic feet

$$\frac{20{,}000}{35} = 571{\cdot}4 \text{ tons.}$$

To construct the curve proceed as follows:—



x = minimum freeboard 2′ 0″. y = freeboard light 9′ 0″.

FIG. 3.—DISPLACEMENT CURVE.

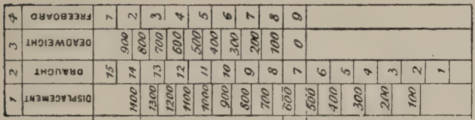


FIG. 4.
VERTICAL DISPLACEMENT AND DEADWEIGHT SCALE.

Through the 2, 4, 6, 8, and 10 feet draughts on the scale draw lines parallel to the line A C. The displacement at the 2 feet waterline is found to be 114·2 tons. Through the point in the horizontal scale of tons representing this, drop a vertical line to the 2 feet waterline. The intersection of these lines gives the first point in the curve. Repeat the same operation for the other displacements at their respective waterlines. A line through the points of intersection gives the displacement curve. For a box-shaped vessel, it is a straight line as shown. Having this, the displacement can be read off at any intermediate waterline between the bottom of the keel and the load waterline. The displacement curve for an actual ship is constructed in the same way. Fig. 3 is an illustration of such an one.

The load waterline in this case is 14 feet above the bottom of the keel, which indicates on the curve 1,400 tons of displacement. The mean draught of the vessel in her light condition is 7 feet, which reads from the curve 550 tons displacement, leaving a carrying capacity or deadweight of (1,400 – 550 =) 850 tons. Let these terms be clearly understood. *The total weight of the ship in whatever condition and floating at any draught is equal to the displacement at that draught. Deadweight is carrying power only*, over and above the actual weight of the ship and her equipment. It, therefore, comprises cargo and bunker coal. *The deadweight of a ship floating at a particular draught is the difference between the displacements in the light condition, and at that draught.*

From the displacement curve an even simpler method of indicating displacement can be arranged, useful more especially to the officer of the cargo-carrying vessel. This is a *Vertical Displacement Scale*, and with it is usually combined a *Deadweight Scale* (see Fig. 4).

Column 2 is a *scale of draughts* exactly similar to the scale of draughts on the displacement curve. Column 1 is a *scale indicating the displacements* corresponding to the draughts, the readings of which are identical with the readings from the curve, since the one is constructed from the other. For example, strike a horizontal line A B from the displacement curve to the vertical scale at, say, 8 feet draught. The reading from the curve gives 655 tons, which is the same on the vertical scale.

Column 3 is a *deadweight scale.* As already pointed out, deadweight is the difference between the displacement at any particular draught and the weight or the displacement of the vessel when light. In the above case the vessel floated light at a mean draught of 7 feet, which represents 550 tons on the displacement scale, while the deadweight stands at *nil.* The difference between the displacements at light draught and at 1 foot intervals above the light draught will equal the respective deadweights at these draughts.

Column 4 represents the *freeboard.* More about this will be found in Chapter VIII. Suffice it for the present to state that by freeboard is meant the distance from the top of the weather deck at midships to the waterline at which the vessel floats. It is, therefore, measured from the deck downwards. In the above case the minimum freeboard was fixed at 2 feet.

Thus, by means of the vertical scale, a ship's officer can read at a glance the total displacement—the deadweight and the corresponding freeboard—at any particular draught.

Tons per Inch Immersion.—Another very useful curve, closely related to the subject of displacement, may be constructed. This is known as the *Tons per Inch Curve.* By "tons per inch" is meant the number of tons necessary to be placed on board or to be taken out of a vessel, to effect an increase or decrease of 1 inch in the mean draught. Thus the term "tons per inch" really means displacement per inch. It is found by calculating the displacement for a foot of the depth at the particular draught at which the vessel is floating, and dividing this by 12. The result is the increase or decrease of the displacement for 1 inch alteration in draught, or "tons per inch."

The area of the waterline in square feet is first found, and reckoning this to be a foot deep, the square feet are at once converted into cubic feet. These cubic feet divided by 35 give the number of tons per foot. Tons per foot divided by 12 give the required "tons per inch."

The formula may be written thus :—

$$\frac{\text{Area of waterline}}{35 \times 12} = \frac{\text{Area of waterline}}{420} = \text{"tons per inch."}$$

The "tons per inch" for the box vessel, for which the displacement curve (Fig. 2) was constructed, would be :—

$$100 \times 20 = 2000 \text{ square feet area of waterline.}$$
$$2000 \times 1 = 2000 \text{ cubic feet of displacement.}$$
$$\frac{2000}{420} = 4{\cdot}7 \text{ "tons per inch."}$$

It will be observed that since a box vessel is unchanging in horizontal section from the bottom to the top, the "tons per inch" will be the same at any draught, thus rendering the construction of a curve unnecessary. This is not so in the case of an ordinary ship. The waterlines, from the top of the keel to the load waterline, all varying in form, necessitate the construction of a curve for readiness and convenience, so that the "tons per inch" may be ascertained immediately for any draught.

This curve is made in the same manner as the displacement curve. The "tons per inch" at the 4, 8, 12, and 16 feet heights above the top of the keel are 8·4, 9·7, 10·36, and 10·6 respectively. Vertical lines are dropped from these positions on the "tons" scale to their respective waterlines, the intersections of which give the points necessary for the construction of the curve (Fig. 5). Its shape is somewhat different from the displacement curve for this reason. With every increase of draught the displacement must increase, and especially in the region of the load waterline, where the vessel is fullest in all ordinarily designed vessels, thus tending to make the curve continue to spread. On the other hand, the "tons per inch" increases rapidly until the vicinity of the load waterline is reached, and then the sides of the vessel, in the case of ordinary cargo steamers, being somewhat perpendicular, there is little variation in the area of the waterlines, and here the "tons per inch" remains about the same, the curve contracting and bending to a vertical position, as shown in the illustration. As an example of how to read the "tons per inch" curve at, say, 6 feet 6 inches draught, strike the horizontal line A B to the curve. At the point of intersection draw a vertical line to the scale of tons, and there is indicated 9·1 "tons per inch."

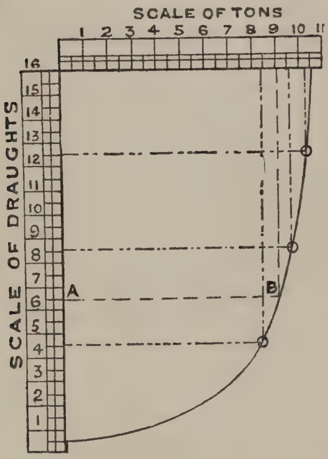


Fig. 5.—"Tons per Inch" Curve.

The use of a curve of "tons per inch" may be illustrated in a variety of ways.

For example, suppose a vessel to be floating at a certain draught, at which the "tons per inch" is 15. On calling at a port a moderate quantity of cargo has to be discharged, the weight of which is not exactly known. After discharging, the mean draught is found to have decreased $4\frac{1}{2}$ inches, therefore the weight of the cargo discharged is $15 \times 4\frac{1}{2} = 67\frac{1}{2}$ tons. Again, supposing a steamer floating at her load waterline, where the "tons per inch" is 15, to consume 100 tons of coal on a voyage, the decrease in draught would be $\frac{100}{15} = 6{\cdot}6$ inches approximately. Every seaman knows that on a vessel passing from salt to fresh water, an increase occurs in the mean draught, and a decrease when passing from fresh to salt water. The reason for this is, that salt and fresh water differ in density, and thus present different supporting qualities to objects floating in them. To support 1 ton of weight requires a displacement of 36 cubic feet of fresh water, while salt water, being denser and heavier, and more capable of affording support, will bear up a weight of 1 ton on a displacement of 35 cubic feet.

Sometimes where the depth of entrance to a dock is limited, it is very necessary to know what change of draught will occur in passing from salt to fresh water, or *vice versâ.* At the load draught this is marked on the ship's side by the Board of Trade, or one or other of the Registration Societies, if the vessel is classed. By the aid of the "tons per inch" curve, we may ascertain the change in draught for ourselves. Suppose a vessel to be floating at a certain draught where the displacement is 4,500 tons, and the "tons per inch" 20. Now, a cubic foot of sea water weighs 64 lbs., and a cubic foot of river water, which is chiefly fresh, about 63 lbs., the difference being $\frac{1}{64}$.* Since the total weight of the ship remains the same, the total weight of water displaced must remain the same also, though as it becomes fresh water it increases in volume, because it is $\frac{1}{64}$ lighter, measure for measure. As already stated, when floating in sea water, she displaces 4,500 tons. Suppose her now to be floating in river water at the same waterline, her weight or displacement will be $\frac{1}{64}$ less.

$$\tfrac{1}{64} \text{ of } 4{,}500 = 70{\cdot}3 \text{ tons.}$$

The "tons per inch" was 20 tons in salt water, but it also will be $\frac{1}{64}$ less.

$$20 \times \frac{63}{64} = 19\tfrac{11}{16} \text{ "tons per inch" in river water.}$$

The change in draught will therefore be—

$$70{\cdot}3 \div 19\tfrac{11}{16} = 3{\cdot}57 \text{ inches.}$$

---

* Pure, fresh water may be taken at $62\frac{1}{2}$ lbs. per cubic foot.

The formula may be shortened, and written thus—

$\frac{1}{64}$ of displacement $\div \frac{63}{64}$ of "tons per inch" = increase in draught;

therefore, $\frac{4,500}{63 \times 20} = 3{\cdot}57$ inches.

Coefficients of Displacement.—In comparing the displacement or underwater form of one vessel with another, it is not sufficient to say that one is long and the other short, one broad and the other narrow, or one deep and the other shallow. Nor is a numerically correct idea conveyed by saying that one is fine and the other full or bluff. A more comprehensive means must be adopted, and this is attained by *coefficients.*

Suppose that out of a block of wood 6 feet long, 1½ feet broad, and 1 foot deep, the model of the underwater form of a vessel be cut out, as shown by Fig. 6, the extreme dimensions of which are—Length, 6 feet; breadth, 1½ feet; depth, 1 foot.

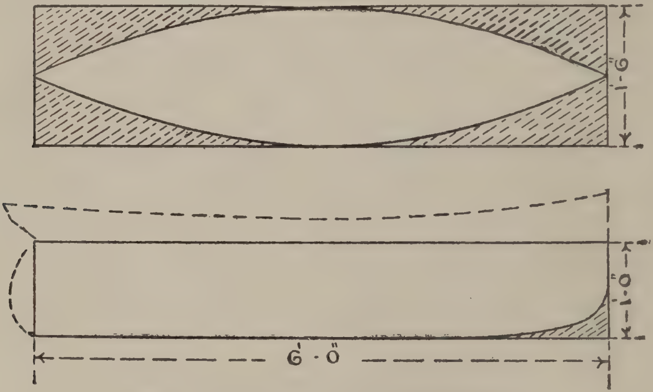


Fig. 6.—Model of Underwater Form.

Before the block was cut, it contained 6 × 1½ × 1 = 9 cubic feet. The extreme dimensions of the remaining part in the form of the model are still the same—6 feet long, 1½ feet broad, 1 foot deep—but much of the volume of the block has been cut away, as shown by the hatched lines, leaving, say, 6 cubic feet, which is $\frac{6}{9} = \frac{2}{3}$, or, as it is generally written, ·66 of the whole block, and this is termed the *coefficient*, or, in other words, the *comparison of fineness.* Thus the coefficient of fineness of any vessel is the fractional part (usually expressed in decimals) which the volume of the displacement bears to the circumscribed block.

·8 would be a very full vessel.
·7 to ·75, an average cargo steamer.
·65, a moderately fine cargo steamer.
·6, a fine passenger steamer.
·5, an exceedingly fine steamer, but an average for steam yachts.
·4, a very fine steam yacht.

By means of coefficients a comparison of the displacement or fineness between two or more vessels may be struck relatively to their circumscribing rectangular blocks.

Vessels of the same extreme dimensions, and the same coefficients of fineness, and, therefore, the same displacements may vary considerably in form or design, which in turn may affect the speed.

Knowing the extreme dimensions of a vessel, and the coefficient of fineness, the exact displacement can easily be arrived at. For example, take a vessel 100 feet long, 20 feet broad, and floating at 8 feet draught, the coefficient of fineness being ·6.

The displacement would be—

$$\frac{100 \times 20 \times 8 \times \cdot 6}{35} = 274 \cdot 2 \text{ tons.}$$

CHAPTER II.

MOMENTS.

Contents.—Moments—Examples of Moments—Centre of Gravity—Effect upon Centre of Gravity of Moving Weights on a Ship, Vertically and Transversely.

Moments.—Moment of a Force about a Point.—We may speak of a ship when inclined from the upright position as having a *moment* tending to bring her to the upright position again. This is usually termed a *righting moment.* On the other hand, it might be found that when the vessel was inclined to a certain angle, she possessed no inclination to return to her original upright position, but continued to heel until she capsized. In this case, we may say she possesses an *upsetting*, or *capsizing moment.*

This important term "moment" is easily understood. Everybody knows the meaning of simple distances like inches and feet, and of simple weights like pounds and tons. We must accustom ourselves to quantities which are got by multiplying distances by weights. Thus, we may have to multiply 5 feet by 8 tons. The product is called 40 *foot-tons.* If we multiply 5 feet by 8 pounds, the product is called 40 *foot-pounds.* If we multiply 5 inches by 8 tons, the product is called 40 *inch-tons.* Now weight is one kind of force, and other forces, such as pressures and resistances (say, wind or steam pressure and water resistance), are also conveniently measured in pounds or tons. And pounds or tons of any kind of force, such as pressure and resistance, may also be multiplied by inches or feet of distance, giving inch-tons, or foot-pounds, &c., as the case may be.

Now the quantity called the *Moment of a Force* (the only kind of moment we want just now) is got by taking some weight or other force and multiplying it by what may be conveniently called its *leverage.* This leverage is the perpendicular distance of the direction in which the force acts from some conveniently chosen point. The point often chosen for this purpose in a ship is the centre of gravity of the ship. For instance, 5 tons of wind pressure on sails multiplied by a leverage from the ship's centre of gravity of 30 feet would give a moment of force about that centre of gravity of 5 × 30 = 150 foot-tons. And a water pressure of 1,000 tons multiplied by a leverage from the same centre of gravity of 3 inches would give a moment of force about that centre of gravity of 1,000 × 3 = 3,000 inch-tons.

Simple illustrations of moments of force may be got from levers.

Let A B (Fig. 7) be a lever 5 feet long, supported at one end, A, as shown, and at the other having a weight of 4 tons suspended at right angles to the lever. In this condition there is a moment about A of 4 × 5 (weight multiplied by distance from centre of weight to point of support) = 20 foot-tons, tending to capsize, or break, or bend the lever at the point A, and the 20 foot-tons in this case may be called a capsizing moment, or a bending moment. Let the lever be subdivided into foot intervals at the points C D E F. If the weight be now moved to the point F, which is 4 feet from A, the moment about A will be 4 × 4 = 16 foot-tons. In like manner, if moved

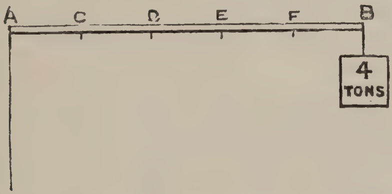


FIG. 7.—WEIGHT ACTING ON A LEVER.

To the point E, the moment about A will be 4 × 3 = 12 foot-tons.
„ D, „ „ 4 × 2 = 8 „
„ C, „ „ 4 × 1 = 4 „
„ A, „ „ 4 × 0 = 0 „

The last, no foot-tons, as will be seen, is accounted for by the fact that the downward force of weight is acting in the same vertical line as the upward support, there being therefore no capsizing moment; or, as we are speaking of a lever or bar, no breaking or bending moment.

There is just another point bearing on moments which will also assist us in studying the structure and strains of ships. In most cases the leverage is the variable factor in influencing the amount of foot-tons, the weight remaining constant. It should now be noticed that the *moment is always greatest at the point of support, and when the weight is removed farthest from it.*

Keeping the weight in the position shown at B, the tendency to fracture at the point C will be considerably less since the leverage is less. The moment at this point is 4 × 4 = 16 foot-tons, and it will continue to diminish until, at the point B, it has vanished completely.

But let us take another simple example illustrative of moments. Fig. 8 represents a lever supported at the point A, and with weights of 3 and 4 tons suspended at its extremities, at distances of 8 and 5 feet respectively from the point of support. First, what would be the tendency to fracture at the point A? On the side towards B there would be a moment of 3 × 8 = 24 foot-tons, and on the side towards C, 4 × 5 = 20 foot-tons.

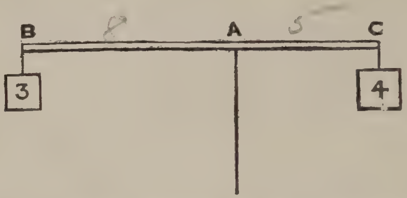


Fig. 8.—Action of Weights on a Point of Support.

But suppose it is asked, "Is there a capsizing moment, and, if so, how much?" As we have already seen, there is a moment of 20 foot-tons on the side towards C and 24 foot-tons towards B, and since the moment towards B preponderates by 24 - 20 = 4 foot-tons, the lever would therefore capsize towards that side.

Centre of Gravity.—But suppose we wished to find the point to which the support must be moved in order that the moments might balance one another, the lever remaining in a state of equilibrium or rest. This would be done by dividing the difference of the two moments, which was found to be 4, by the total weight 3 + 4 = 7, 4 divided by 7 = $\frac{4}{7}$ foot, and moving the support this distance towards B, the side possessing the greater moment. Let us prove this. The support, according to our calculation, will now be $8 - \frac{4}{7} = 7\frac{3}{7}$ feet from B, and $5 + \frac{4}{7} = 5\frac{4}{7}$ feet from C.

Towards B the moment is now $3 \times 7\frac{3}{7} = 22\frac{2}{7}$ foot-tons.
" C " $4 \times 5\frac{4}{7} = 22\frac{2}{7}$ "

Being exactly equal to each other, the lever remains at rest. Now this *balancing point* or *centre of moments* is a very important point. For the point at which a body (acted on only by its own weight) will balance is called the *centre of gravity of that body.* And the point at which a system of bodies (acted on only by their own weight) will balance is called the *centre of gravity of that system of bodies.* An example of a system of bodies is a ship with or without cargo in her. And as such a body as a ship cannot be balanced experimentally so as to find the centre of gravity by trial, the calculation of the moments in question is employed upon the ship and the weights in her until their balancing point is found, and that balancing point is the centre of gravity of the ship and the load then in her, and the whole weight of ship and cargo may be supposed to act vertically downwards through that point.

For, proceeding further, in Fig. 9, AB is a lever, with a weight of 2 tons at a distance of 2 feet from the support, and a weight of 4 tons at a distance of 4 feet from the support, both on the same side, and, similarly, weights of 2 and 4 tons at 2 and 4 feet respectively on the other side of the support. Then the moments must be the same, and it is evident that the lever is supported at the centre of gravity of the total weight. Let a weight of 3 tons be now suspended from the extremity of the lever at B, and at a distance of 6 feet from the support, as shown by the dotted square. It is required to find the centre of gravity now. Since the moments preponderate towards B by $3 \times 6 = 18$ foot-tons, if this be divided by the sum of the weights, we shall get the distance the centre of gravity has moved, which is $\frac{18}{15} = 1\frac{1}{5}$ feet towards B.

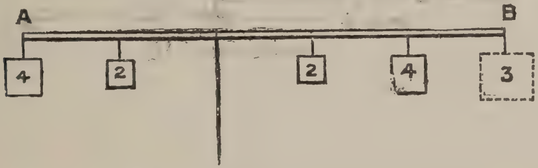


FIG. 9.—CENTRE OF GRAVITY.

But suppose that instead of a weight being added, the 2 ton weight on the side towards B be removed. Let us find the centre of gravity now. The moment towards A will preponderate by $2 \times 2 = 4$ foot-tons, and this, divided by the total weight, which is $2 + 4 + 4 = 10$, will equal $\frac{4}{10} = \frac{2}{5}$ foot = shift of centre of gravity towards A.

The reader is advised to make himself thoroughly familiar with the principle of moments, as illustrated in this chapter, as this will be found to be absolutely essential in order to deal successfully with the following chapters. Whenever several weights are connected by any means, as shown in the foregoing examples, the combined system of weights acts directly through one balancing point, and this is their Common Centre of Gravity. And, if this method of finding the common centre of gravity of a ship and its load be used, one first finds how far from stem or stern that centre of gravity lies, and how much it is shifted fore or aft by shifting weights fore and aft. And precisely the same sort of calculation may be used to find how far above the keel the same centre of gravity lies, and how much up and down it is shifted by shifting weights up and down in the ship. We have only in this case to measure our leverages vertically above and below the balancing point we are trying to find by assuming a point for its position, and multiply the weights by the vertical leverages to get the moments. We, therefore, now proceed to show how to apply these principles to actual ships.

Effect of Moving Weights on a Ship's Centre of Gravity.—Suppose a vessel be floating with her centre of gravity at the point, G (Fig. 10). (It may be said here that the position of the centre of gravity of the ship when light could be supplied by the builder, and this would limit the duty of the shipmaster to finding the position of the centre of gravity with various kinds of loading. But as it is not customary with all shipbuilders to do this, a simple experiment by which the shipmaster himself may find the centre of gravity will be given later on). Her *total displacement*—that is, her *weight*—is 1,000 tons. Let a weight of 30 tons, already on board, be raised from the hold and placed on the deck, at a distance of 20 feet from its former position, as shown. What effect will this have upon the centre of gravity? Since the centre of gravity is in the centre of the total weight it is evident that, *if a weight be raised, the centre*

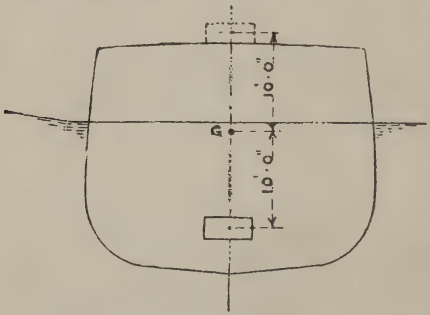


FIG. 10.—CENTRE OF GRAVITY OF A SHIP.

of gravity must travel in the direction of the moved weight. To find the exact distance the centre of gravity has moved, the same rule is adopted as in the case of a vertical lever. *Multiply the weight moved by the distance it is moved, and divide the result by the total weight or displacement.*

$$\frac{30 \times 20}{1000} = \frac{600}{1000} = \cdot 6 \text{ foot,}$$

the distance the centre of gravity has been raised.

Again, suppose the weight, instead of being placed on deck, had been taken out of the vessel altogether. In this case, *multiply the weight by its given distance from the centre of gravity of the ship*, say, 10 feet, and *divide by the total displacement after the weight is removed.* (1000 − 30 = 970 tons = displacement after weight is removed).

$$\frac{30 \times 10}{970} = \frac{300}{970} = \cdot 3 \text{ foot,}$$

the distance the centre of gravity has been raised.

Again, suppose, when the displacement is 1000 tons, a weight of 30 tons be placed on board 10 feet below the centre of gravity. *Multiply the new weight by its distance from the centre of gravity*, and *divide by the new displacement* (1000 + 30 = 1030 tons = new total displacement).

$$\frac{30 \times 10}{1030} = \frac{300}{1030} = \cdot 28 \text{ foot,}$$

the distance the centre of gravity has been lowered.

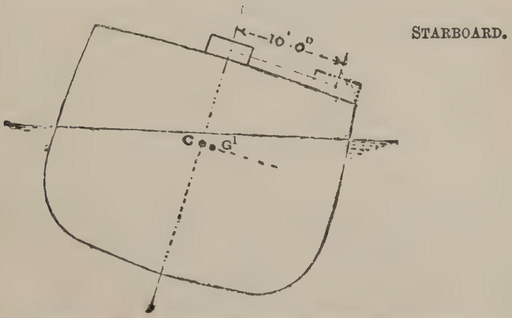


FIG. 11.—EFFECT OF WEIGHT MOVED ATHWARTSHIPS.

Let us now notice the effect of a weight moved athwartships (Fig. 11).

The centre of gravity is in the position shown at G, and the total displacement is 1000 tons.

A weight of 20 tons already on board, on the centre of the upper deck, is moved 10 feet to starboard. The centre of gravity must move in the same direction, and in a line parallel to the line joining the centres of the weight in its original, and in its new position. To find the exact distance moved, *multiply the weight by the distance moved*, and *divide by the total displacement.*

$$\frac{20 \times 10}{1000} = \frac{200}{1000} = \cdot 2 \text{ foot,}$$

(GG^1), the distance the centre of gravity has travelled to starboard

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CHAPTER III.

BUOYANCY.

Contents.—Buoyancy—Water Pressures—Reserve Buoyancy—Sheer—Value of Deck Erections—Centre of Buoyancy—Curves of Vertical and Longitudinal Centres of Buoyancy—Effect upon a Ship's Centre of Buoyancy of Immersing, or Emerging Wedges of Buoyancy—Effect of Entry of Water upon Buoyancy—Camber, or Round of Beam.

Buoyancy.—*Buoyancy* means *floating power*. Under what condition will a vessel float? Simply, when its enclosed volume is greater than its total weight in tons multiplied by 35, since it requires a displacement of 35 cubic feet of salt water to support 1 ton. If the enclosed watertight volume of the vessel in cubic feet is *less* than its total weight in tons multiplied by 35, it will be evident that the vessel will sink. This we have learned from the Chapter on "Displacement." But it may be asked, "*Why* does a vessel float?" This we shall now endeavour to explain.

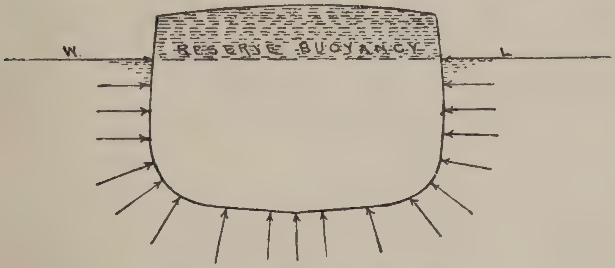


Fig. 12.—Buoyancy of a Ship

Water Pressure.—Let Fig. 12 represent a ship floating in water at the waterline, W L. Upon the whole of the immersed surface of the skin of the vessel the water is pressing in lines of force square to the surface—longitudinally, transversely, obliquely, and vertically—as shown by the arrows in the figure, *tending* to crush in the sides, ends, and bottom, or to push the vessel out of the water. This is understood more clearly when it is remembered that immediately any floating object is taken out of the water, the water rushes in on all sides, and more quickly than can be seen, the cavity formerly occupied by the object is filled, and the water is again at its uniform level.

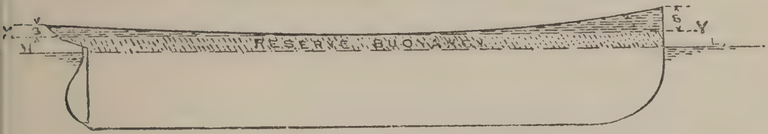
Thus, while a ship is floating, the water has still the inclination, if the phrase may be so used, to occupy the space filled by the immersed part of the vessel. Why the water does not succeed in crushing in the exterior of the vessel, will be dealt with in another Chapter on "Structure." Why it does not succeed in thrusting the ship out of the water is explained by the fact that there is the downward pressure of the weight of the ship itself. Thus a vessel will sink to a draught, such that the sum of the *upward* pressures of buoyancy exactly equals the weight of the ship, the two balancing each other. The forces of this buoyancy, measured in tons, are therefore equal to the weight of displacement.

Reserve Buoyancy.—Let it be imagined that a vessel floating at the waterline where the "tons per inch" is, say, 12 tons, has an additional weight of 60 tons placed on board. The result will be that the weight of the vessel has increased 60 tons in excess of the buoyancy, and she must sink. But how far? Well, since we have observed that 1 ton of buoyancy equals 1 ton of displacement, she will therefore sink until she has displaced 60 tons more water, which is an increase of $\frac{60}{12}$, or 5 inches in the draught. It is evident then that the buoyancy pressures increase with depth.

If, on the other hand, 60 tons be taken out of the vessel, the buoyancy will now be 60 tons in excess of the displacement, the result being that the vessel will rise out of the water until the buoyancy is reduced by 60 tons, and the draught is decreased by $\frac{60}{12}$, or, 5 inches.

Thus, we have here one of the conditions of a vessel floating at rest in still water—namely, that *the total weight of the vessel equals the total weight of the water displaced*, or the *buoyancy.* The buoyancy of the immersed portion of the vessel represents that which is requisite to keep her afloat. The buoyancy of all enclosed watertight space above the waterline is therefore surplus buoyancy, or safety buoyancy, or, as it is more commonly termed, *Reserve Buoyancy* (see Figs. 12 and 13).

Sheer.—It is not sufficient that a vessel have just enough buoyancy to keep her afloat, for if she had only this, every wave would submerge her. It is the surplus buoyancy that gives her rising power, and, as we shall see in Chapter VI., provides righting power when inclined. The great advantage of sheer (Fig. 13), which gives surplus buoyancy at the ends of a vessel, will now be evident, for every time the vessel pitches into the trough of a sea, she immediately displaces more water than her weight, and is, therefore, thrown up again.



S = Sheer. *Volume above line X, Y = Reserve buoyancy obtained by sheer.*

FIG. 13.—SHEER.

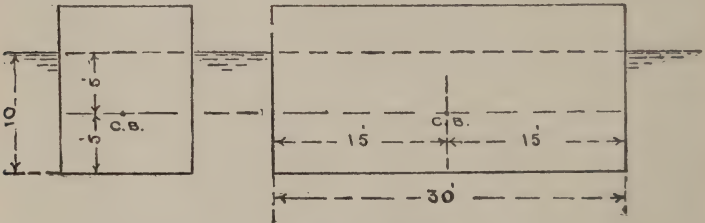
Value of Deck Erections.—The Board of Trade recognises this to such an extent as to enforce a certain amount of sheer, according to the type of the vessel. When this amount is exceeded, a reduction in the freeboard is allowed, and when the sheer is less an addition is made to the freeboard (see Chapter on "Freeboard"). The value of poops and forecastles, especially the latter, and particularly if efficiently closed at the ends, will now be clearly understood, since they all add to the buoyancy, and at those parts of the vessel where it is greatly needed. Though not to the same extent in efficiency, yet all bridges with watertight ends, and deck houses and hatches—in short, all enclosed watertight erections afford reserve buoyancy.

Centre of Buoyancy.—Now, just as the Centre of Gravity of the weights ranged on a lever can be ascertained, as explained in the previous chapter, so the centre of action of the numerous forces of buoyancy may be found, and since the forces acting upon any body may always be supposed to act directly through the centre of action, the value of this point will be readily granted, especially when we come to deal more closely with the subject of Stability.

However, instead of speaking of the centre of action of the forces of buoyancy, this point is, for brevity, termed the *Centre of Buoyancy*, and, moreover, it is found that the centre of buoyancy is the centre of displacement. Thus, to find the centre of buoyancy it is simply necessary to calculate the centre of displacement, as the two names indicate exactly the same point. The centre of buoyancy being the centre of the displacement, it must vary in position with every variation of draught, so that it becomes necessary to arrange a convenient method of readily ascertaining the centre of buoyancy at any draught. This is done by calculating the centres of buoyancy at several draughts parallel to the load waterline, and constructing curves. By means of a calculation of moments, using horizontal areas of waterlines, instead of weights as in the case of the lever examples in the previous chapter, the positions of the vertical centres of buoyancy are found at the required draughts. In a similar manner the longitudinal centres of buoyancy at several draughts are calculated, and by using vertical areas of transverse sections of displacement at regular intervals fore and aft instead of weights, the several longitudinal centres of buoyancy may be found.

Curves of Vertical and Longitudinal Centres of Buoyancy.—Thus, to find the actual centre of buoyancy, it is necessary to construct two curves, one for the *vertical centres of buoyancy*, to give vertical position, and the other for the *longitudinal centres of buoyancy*, giving longitudinal position. The intersection of the two lines is the point required.

However, since these curves can easily be supplied to the ship's officer by the shipbuilder or naval architect, it is unnecessary and outside the aim of this book to enter into the minute details of the actual calculation. What the seaman requires is to understand how to ascertain the centres of buoyancy from these curves, and to know how to use them when obtained.



C.B. = Centre of buoyancy.

FIG. 14.—CENTRE OF BUOYANCY OF BOX-SHAPED VESSEL.

To construct curves for a box-shaped vessel would be unnecessary, as it is evident that the vertical centres of buoyancy must always be at half the draught (see Fig. 14), and the longitudinal centres of buoyancy at the middle of the length if floating with the bottom parallel to the waterline.

Thus, at 10 feet draught the vertical centre of buoyancy is 5 feet down from the waterline, at 6 feet draught it is 3 feet down from the waterline, and so on.

Curve of Vertical Centres of Buoyancy.—The heights of the vertical centres of buoyancy used in the construction of the curve in Fig. 15 are for a vessel about 200 feet long, and with a draught of 14 feet when fully loaded. Suppose the

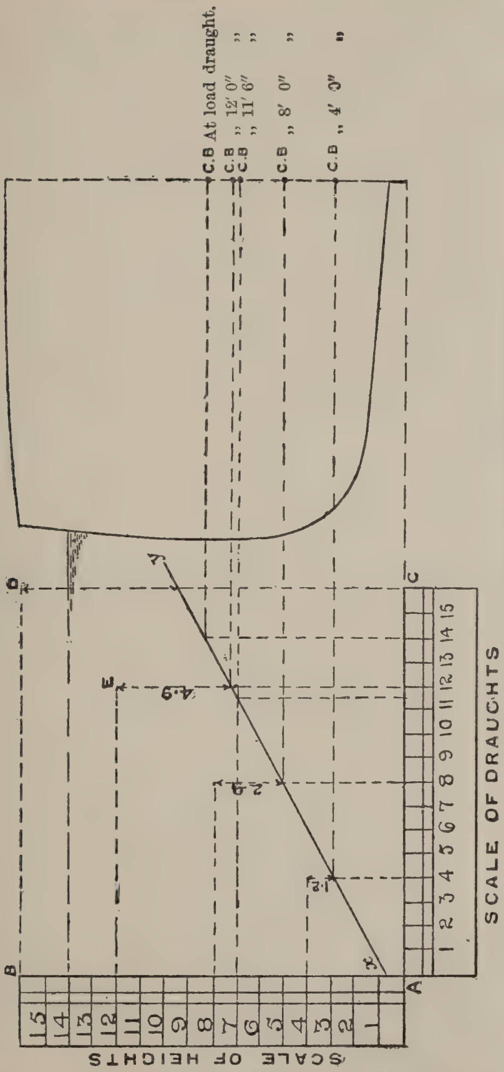


FIG. 15.—CURVE OF VERTICAL CENTRES OF BUOYANCY.

vertical centres of buoyancy at the 4, 8, 12, and 16 feet draughts are found to be 1·2, 2·9, 4·9, and 6·6 feet respectively below their respective waterlines. To construct the curve proceed as follows:—Draw the lines A B and A C at right angles to each other. Let A B represent a scale of heights and A C a scale of draughts. Through the 16 feet height in the scale A B draw a horizontal line as shown, and through the 16 feet draught in A C draw a vertical line intersecting the other at D. From the point D set down the distance of the centre of buoyancy below the 16 feet waterline = 6·6 feet. Proceed in the same manner for the 12 feet waterline. Through the 12 feet height draw a horizontal line, and through the 12 feet draught draw a vertical line intersecting the other at E. From E set down the distance of the centre of buoyancy below the 12 feet waterline = 4·9 feet. In a similar manner the centres of buoyancy at the 8 and 4 feet waterlines may be set off. Through these points draw the line $x\,y$, which is *the curve of the vertical centres of buoyancy* required. By means of it the height of the vertical centres of buoyancy above the bottom of the keel may be read off at any draught.

It will be understood that the curve constructed for any particular vessel will be of little use for any other vessel unless of exactly the same form and proportion in the immersed protion of the hull. But for the sake of example, let the curve in Fig. 15 be for a yacht with a rising keel and drawing 10 feet forward and 13 feet aft. This represents a mean draught of $\frac{10 + 13}{2}$ = 11 feet 6 inches. At 11 feet 6 inches on the horizontal scale of draughts, set up a vertical line until it intersects the curve of the centres of buoyancy. From this point draw a horizontal line until it meets the vertical scale of heights, and there we read 7 feet, which is the height of the vertical centre of buoyancy above the bottom of the keel. Had the vessel been an ordinary cargo one, floating on even keel, and drawing 11 feet 6 inches fore and aft, the height of the centre of buoyancy would have been the same. As has already been stated, this point, taken by itself alone, is of little use to any one. It is only when used in relation to other points, with which we shall deal, that it possesses importance.

Curve of Longitudinal Centres of Buoyancy.—The longitudinal centres of buoyancy for the same vessel of which Fig. 15 is the curve of the vertical centres of buoyancy are found to be 98·7, 99·2, 99·8, and 100 feet from the afterside of the stern post at the 16, 12, 8, and 4 feet waterlines respectively.

The curve would be constructed in the following manner:—

Draw the vertical line A B, and upon it construct a scale of draughts. From B draw the horizontal line B C, and upon it construct a scale of feet, long enough to include the greatest distance of the centre of buoyancy from the stern post, which in this case is 100 feet. 98·7 feet on the line B C gives the first point in the curve. At 12 feet draught draw a horizontal line, and through the point in the scale indicating 99·2 feet drop a vertical line. The point of intersection gives the second point in the curve. Proceed in the same manner with the 8 and 4 feet waterlines, obtaining the points indicated by the large dots. Through these points draw the line x y, which is *the curve of the longitudinal centres of buoyancy.* Supposing we are asked to read off the longitudinal centre of buoyancy at, say, 7 feet 6 inches draught, we draw the horizontal line from the 7 feet 6 inches height in the scale of draughts until it intersects the curve, and from this point we strike a vertical line to the scale of distances, and there is indicated 99·6 feet from the after side of the stern post. From this curve we can see that since the vessel is 200 feet long, the displacements of the fore and after bodies are exactly equal at the 4 feet draught, as the vessel's centre of support (centre of buoyancy) is at the middle of the length. Then, as the draughts increase, we notice that the centre of buoyancy travels a little towards the stern, showing that the after body is slightly fuller than the fore body, increasing in this respect up to the load waterline. Now, we have

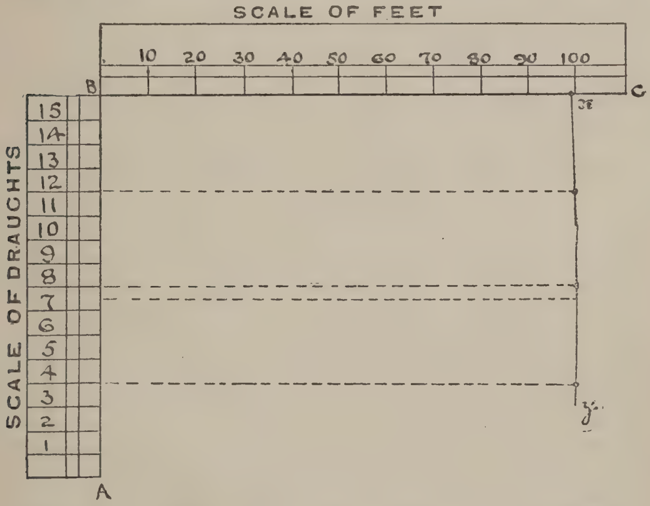


FIG. 16.—CURVE OF LONGITUDINAL CENTRES OF BUOYANCY.

simply reduced our ship to a huge lever, balanced practically at the centre when floating at 7 feet draught. Suppose in this condition the vessel weighs 550 tons, this being her displacement. She is then to be additionally loaded in the following manner :—

50 tons are placed 20 feet abaft of the longitudinal centre of buoyancy.
30 ,, ,, 60 ,, ,, ,, ,,
20 ,, ,, 30 feet forward ,, ,, ,,
40 ,, ,, 70 ,, ,, ,, ,,

What effect will this have? First of all, we know that the draught will be increased. This could be found before the weights are placed on board, by adding the weights together, and referring to the displacement scale in Figs. 3 and 4.

550 + 50 + 30 + 20 + 40 = 690 tons, which reads 8 feet 4½ inches mean draught.

There may be another effect. If the moments of the weights preponderate ahead or astern of the centre of buoyancy, then the vessel will trim* by the head or the stern, as the case may be. Let us see—

Moments on after side of Centre of Buoyancy.	*Moments on fore side of Centre of Buoyancy.*
50 × 20 = 1000 foot-tons.	20 × 30 = 600 foot-tons.
30 × 60 = 1800 ,,	40 × 70 = 2800 ,,
Total, 2800 ,,	Total, 3400 ,,

Then, since the moments preponderate on the fore side by 3,400 − 2,800 = 600 foot-tons, the vessel will trim by the stem.

But suppose we now wish to know what weight must be placed at, say, 25 feet aft of the centre of buoyancy to bring the vessel again on even keel—that is, with the new load line parallel to the keel. This would be discovered by dividing the foot-tons in excess by the distance the new weight has to be placed from the original centre of buoyancy. The result will be the required weight—

$$\frac{600}{25} = 24 \text{ tons.}$$

It will now be seen that the moments on each side of the centre of buoyancy are equal.

Vessels passing from salt or sea water to fresh or river water increase in draught. The reason of this has already been explained.

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* By *trim* is meant the difference between the draught at the stem, and the draught at the stern.

Effect of Wedges of Buoyancy on Ship's Centre of Buoyancy.—Another thing which may be observed is, that not only do some vessels change draught in passing from sea to river water, but that they also change trim. The reason of this will be evident when it is known that in some vessels the fore body is fuller, and has more displacement than the after body. Therefore, in increasing in draught, the longitudinal centre of buoyancy will travel forward (since it must remain in the centre of displacement), and the fore end of the vessel, having more support, will sink less than the after end. Hence, the change of trim.

In lecturing before ships' officers, the question has more than once been asked, Is it possible with a vessel trimming by the stern and the centre of the disc on the load waterline, to place any more cargo on board and yet not submerge the disc, and, consequently, not increase the draught?

To such a question it is certainly possible to answer "yes," but such a vessel would be so exceptional in her design that the answer is practically "no."

For on examination of the lines of ordinary vessels, it is generally found that the fore body is slightly fuller than the after body, but this fulness takes place usually on the lower lines. At the region of the load line, however, the greatest fulness is usually aft, so that, imagining the vessel to be floating first at the waterline W L (Fig. 17), and then by shifting weights forward to float at A B, the wedge y would generally be of greater volume than x.

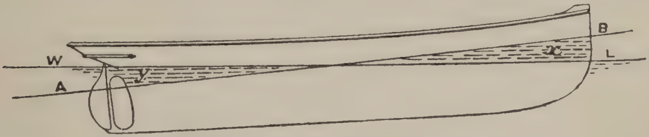


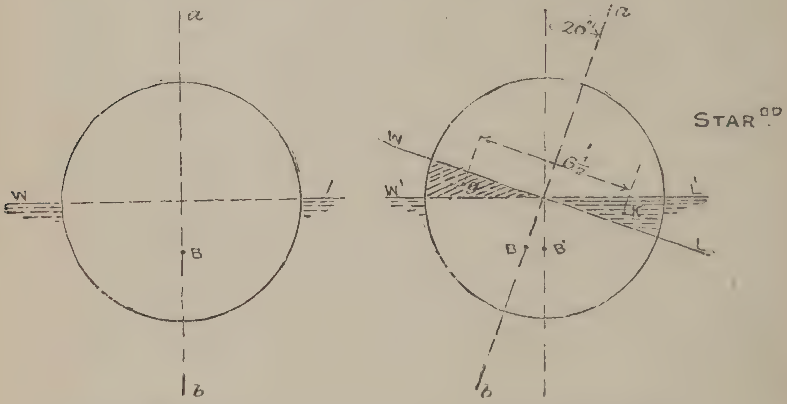
FIG. 17.—WEDGES OF BUOYANCY.

We have already seen that before a vessel will float at rest at any waterline, the weight of displacement and the buoyancy must equal each other. If by any means the weight of displacement be increased, the vessel will increase in draught; if by any means the buoyancy be increased, the vessel will rise out of the water, and the draught will be decreased.

Thus it follows that if the fore wedge x be less in volume than the aft wedge y, the draught would actually be slightly increased since the buoyancy is less. If x and y be equal, no change will take place in the draught, and only when x is greater than y

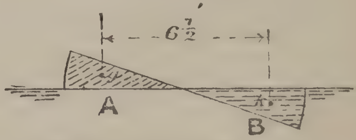
would any reduction in the mean draught be observed. Such is not likely to occur except in ill-designed vessels, for the effect upon the speed by the production of great resistance would certainly outweigh the consideration of carrying a trifle more deadweight at such a cost.

Again, suppose the vessel to be floating at the waterline A B, and weights to be then shifted aft, so that the waterline is now at W L. If the volume of the immersed wedge y is more than the emerged wedge x, the draught will be somewhat decreased, and if y be less than x, an increase in draught would occur. We have observed that the vertical centre of buoyancy is the vertical centre of the displacement, and that with every transverse movement of the vessel (whether by means of external force in river or dock, or under the influence of wind or waves) there is a corresponding movement of the centre of buoyancy into the new centre of displacement. We shall now see how this new position may be found, and in this again the study of moments (Chapter II.) comes to our assistance.



Cylinder floating upright.

Cylinder inclined to 20°.



Wedges of immersion and emersion.

FIG. 18.—WEDGES OF BUOYANCY IN A CYLINDER.

Fig. 18 is a cylinder 10 feet in diameter, 20 feet long, and floating at 5 feet draught. The displacement in this condition would be $\frac{1}{2} \times 10^2 \times \cdot 7854 \times 20 = 785 \cdot 4$ cubic feet. B is the centre of buoyancy when floating upright. Let the cylinder be inclined to an angle of 20°. Observe clearly what takes place. W L was the original waterline; after the inclination the waterline is W′ L′, so that the wedge A, which was previously actual buoyancy, has come out of the water and become reserve buoyancy, and the wedge B, which was formerly reserve buoyancy, has become actual buoyancy. (Let g and k be the centres of buoyancy of each of the wedges). This simply amounts to shifting the wedge of buoyancy, with g as its centre, to the position of the wedge, with k as its centre, a distance of about $6\frac{1}{2}$ feet. Let the wedge, with g as its centre, equal 87 cubic feet, and, as just stated, the distance from the centre of buoyancy of the emerged wedge to the centre of buoyancy of the immersed equal $6\frac{1}{2}$ feet. As the volume of displacement must be the same, at whatever angle of inclination, it follows that the wedge, with k as its centre, will equal 87 cubic feet. Now the new centre of buoyancy of the whole figure must have travelled in the direction in which the actual buoyancy was shifted; that is, to starboard of its original position in the figure—viz., to B^1, and in a line parallel to the line joining g and k, the centres of the wedges. The exact distance may be found by *multiplying the volume of the wedge of buoyancy moved*, 87 *cubic feet, by the distance moved*, $6\frac{1}{2}$ *feet*, and *dividing by the total volume of displacement;* or, in other words, *the volume of buoyancy.*

$\frac{87 \times 6\frac{1}{2}}{785 \cdot 4} = \cdot 72$ feet, centre of buoyancy moved to starboard.

In coming to vessels of ship form, the principle of finding the shift of the centre of buoyancy is exactly the same, but there is a difference in the wedges. In one respect, however, the two wedges in any one ship do not differ, and that is, that the volume of the wedge of immersion is always equal to the volume of the wedge of emersion. In cylindrically-shaped vessels, whose waterline passes through the centre of the cylinder, revolving as they do on the centre of their diameter, not only are the wedges equal in volume, but identical in shape, any sections of the wedges all fore and aft being exactly similar. This is not so with vessels of ship form, for in these the wedges of immersion and emersion vary very considerably in form, especially towards the ends, and even more so still if the angle to which the vessel is inclined be great.

A little thought or personal observation of the actual form of a ship's hull will make this the more clear.

Thus, while it is a simple matter to find the centre of gravity of the wedges of immersion and emersion of a floating cylinder—whose waterline passes through the centre of the cylinder—it entails more work to find the corresponding points in an actual ship; and, while outside the sphere of this book, it is a simple enough matter for the naval architect or shipbuilder.

Effect of Entry of Water upon Buoyancy.—There is still another aspect of the subject of buoyancy which calls for some attention. Suppose, first of all, that by some means or other a quantity of water enter the hold of a vessel. What will be the effect? This will all depend upon how the water entered. Let us imagine that the sea breaking over the bulwarks entered by means of some deck opening—hatchway, for instance—the outside shell plating of the vessel being intact and perfectly watertight. The result of water finding ingress in this way would exactly resemble the result of loading cargo, the water being deadweight at the rate of 35 cubic feet to 1 ton. Should water continue to enter the vessel, the draught would gradually increase until, if it happened that the total weight of the vessel, cargo, and water in her were more than the maximum possible displacement, she would naturally sink. If, on the other hand, when the hold was filled, the total weight of the vessel and the water in her were less than the maximum possible displacement, she would remain afloat—that is, disregarding the effect such might have upon the stability of the vessel, and also taking it for granted that little change of trim took place; for otherwise, should the water find ingress into a large hold towards the end of a vessel, this might result in her going down by the head or stern, as the case might be. But let us take an entirely different case. Supposing the outside plating in the way of some hold be damaged below the load waterline, the sea would consequently rush in. If the hold were empty, it would fill, unless prevented, up to the level of the outside sea level, with water. But this is different from the former case, where water was poured into the hold from above. There the water acted as deadweight, but not so in this example, as there is now free communication between the water in the hold and the sea outside. What has happened is this? The vessel has been robbed of the total buoyancy, both actual and reserve, of this compartment, even though it be found that, after increasing in draught, she still floats with considerable freeboard. The empty space from the water in the hold to the top of the hatchway, as stated, is no longer reserve buoyancy, and the vessel has lost the entire buoyancy of this compartment; and if it happens that the total buoyancy of the other intact compartments of the vessel is greater than the total displacement, as it was before the structure was damaged, and before the water entered, the vessel will float. If, on the contrary, the vessel possesses less remaining buoyancy than this, she will be entirely immersed, and will sink. This will perhaps be somewhat clearer if illustrated by a box vessel, as shown in Fig. 19. The vessel is divided into three watertight compartments by two watertight bulkheads, and floats at the waterline, W L. The centre compartment is damaged, and its actual and reserve buoyancy entirely lost, the sea having free entrance. If the sum of the volumes of A A (the reserve buoyancy) and B B (parts of the original actual buoyancy) be at least equal to the original actual buoyancy—that is, to the whole of the volume below the original waterline—it is possible for the vessel to float; if it be less, she will inevitably sink.

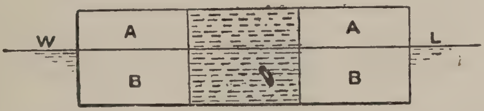


FIG. 19.—EFFECT ON BUOYANCY OF ENTRY OF WATER INTO A DAMAGED COMPARTMENT.

The reader must bear in mind that the inflow of water into such a hold as this has added nothing whatever to the weight of the ship, although the draught has increased; the weight, or the total displacement, remains exactly the same, but the entire empty space in the damaged hold is to be left out altogether, and ignored in reckoning upon the actual and reserve buoyancy. In increasing her draught, the vessel has simply taken from the reserve buoyancy in the other watertight and intact compartments a volume equal to the volume of that part of the damaged compartment which was previously below the waterline, and which was, therefore, previous to the accident, in use as actual buoyancy.

Again, suppose this accident happened to the vessel when her hold was filled with cargo, say timber, for example. How does she stand now? The water will flow into the hold, and occupy what space it can. This will naturally be very small indeed, since the hold is already practically full. As the water cannot possibly occupy the space taken up by the timber, it has to be content with what remains. Therefore, the volume below the original waterline of all the corners and crevices not occupied by the timber is lost actual buoyancy, and the vessel will sink until she has taken from the reserve buoyancy a volume equal to the volume of the space unoccupied by the timber, and below the original waterline, which, in most cases, would be comparatively little.

Camber or Round of Beam.—Vessels classed at Lloyd's require that all weather or uppermost decks have a round upon them, or camber, of at least $\frac{1}{4}$ inch to 1 foot of beam. Thus, a vessel of 40 feet beam will have a camber of $\frac{1}{4}$ inch × 40 = 10 inches, and will, therefore, be 10 inches deeper at the middle of the breadth at midships than at the sides. One important advantage to be gained by this is an addition to the reserve buoyancy, and, little as it may seem, its importance is so recognised, that if the stipulated amount of camber be reduced, an increase of freeboard is demanded ; if the amount be exceeded, a reduction in the freeboard is allowed (see Chapter on "Freeboard").

CHAPTER IV.

STRAIN.

Contents.—Relation of Weight of Material in Structure to Strength—Strain when Floating Light in Dock—Relation between Weight and Buoyancy—Strain Increased or Decreased in Loading—Distribution and Arrangement of Material in Structure so as to get Greatest Resistance to Bending—Types of Vessels Subject to Greatest Strain—Strains among Waves—Panting Strains—Strains due to Propulsion by Steam and Wind—Strains from Deck Cargoes and Permanent Weights—Strains from Shipping Seas—Strains from Loading Cargoes Aground.

Relation of Weight of Material in Structure to Strength.—It would be rather absurd to commence the study of the structure of ships—whether they be steamers, sailing ships, or yachts — before first having some knowledge of the strains which, under varying circumstances, they would most probably have to bear. To build a ship capable of enduring, without damage to its structure, every possible strain which might be brought to bear upon it, however excessive, would necessitate the introduction of such an amount of heavy material into its structure as to render it greatly deficient in its carrying capacity. It does not even follow that the vessel with the heaviest material is necessarily the best, or even the strongest, ship, but rather the one with the lightest material so combined as to give the maximum strength and efficiency, and sufficient to cover the strains which in all likelihood, under reasonable circumstances, would have to be endured. This is the aim of all such classification societies as Lloyd's, Bureau Veritas, The British Corporation, &c.

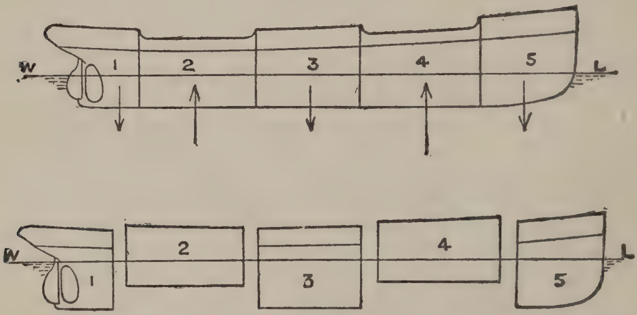
Ships are built on a combination of two systems of framing—viz., longitudinal and transverse.

Longitudinal framing includes all those structural parts of a vessel which run in a fore and aft direction, and afford longitudinal strength.

Transverse framing includes all material giving transverse or athwartship strength.

As has been already indicated, the strongest ship is only obtained when these two systems have been intelligently woven together, the strength of the one co-operating with the strength of the other—that is, in relation to the work which they have to do. When this is accomplished the whole is then covered by a skin in the form of a shell-plating and decks, and by this means the skeleton or framework of the ship is still further united and strengthened.

Strain when Floating Light.—Looking at an ordinary cargo steamer floating in the dock in her light condition, and lying at rest at her moorings, one would almost imagine at first sight that she is perfectly free from strain. But on investigation this is found not to be so. As has been previously shown, any object placed in water, whether it be a ship or a log of wood, will sink until it has displaced a volume of water equal in weight to itself. Or, in other words, before the object will remain stationary, and at rest at any waterline, the downward pressure of the weight of the object floating must be exactly balanced by an equal upward pressure of the water.



Figs. 20 and 21.—Strains on Vessel Floating Light.

Relation between Weight and Buoyancy.—Supposing the vessel shown in Fig. 20 be 200 feet long, and classed at Lloyd's, she would require four watertight bulkheads, one at each end of the engine and boiler space, a collision bulkhead at the fore end, and another bulkhead at the aft end. The weight of the vessel light being, say, 500 tons, if placed in the water would displace a volume of water 500 tons in weight, and would thus remain stationary, say, at the waterline, W L.

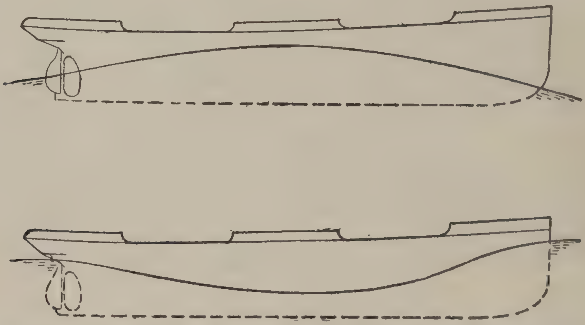
But suppose the vessel could be divided off into five separate parts at the four watertight bulkheads, and each part floated separately, as shown in the sketch (Fig. 21). It will now be seen that the draughts vary for each part, and none of them float at the original waterline. A little observation will soon explain this. The total weight of all the parts is exactly the same, and therefore the total water displaced is the same; but throughout the length of the vessel there is an unequal distribution of weight and buoyancy. Thus, for example, referring to the sketch, parts 1 and 5—the ends of the vessel—being very fine, and yet of considerable weight, which is increased by the poop and forecastle, in order that they may be balanced by the buoyancy they will have to sink to the draught as shown. In parts 2 and 4 we have the vessel rapidly increasing in internal capacity or fulness, and small in weight in comparison with the volume of the enclosed space, the result being that these parts float at a less draught than previously. In No. 3 we have the fullest part of the vessel with greatest floating power. But in this compartment is concentrated the weight of engines and boilers, which tends to increase the draught upon what it is in the combined ship. Thus we see that throughout the length there is a series of upward and downward vertical strains, as shown by the arrows, tending to alter the form of the vessel longitudinally. Note that these strains *tend* to alter the form of the vessel. This affords one consideration for the naval architect or shipbuilder, in constructing an efficient ship—namely, that there is sufficient strength to prevent any such alteration in form taking place, or even any sign of such strain being endured.

Strains in Loading.—Now it can easily be seen how these strains may be considerably increased when loading; for instance, if in the case of a miscellaneous cargo the heavy weights be placed towards the ends of the vessel where the buoyancy is least, the tendency of the ends of the vessel to droop would be greatly aggravated. The endeavour should be to distribute the heavy weights of the cargo so as to produce a balancing effect between the forces of weight and buoyancy, and thus avoid great local excess. By this means it is possible to reduce the strain even from what it is in the light condition. In considering strains at sea, the evil of bad loading will be seen still more clearly.

In addition to these vertical strains to which the vessel is subject while lying at rest, there are collapsing strains acting upon every portion of the immersed skin of the ship (see Fig. 12, Chapter III.). For, be it remembered that the forces of buoyancy act in perpendicular lines to the immersed surface. Thus, while there is an upward pressure tending to thrust the vessel out of the water, there are also horizontal and oblique forces tending to crush in the sides of the ship.

It will be obvious that the greater the immersed girth of the vessel, the greater the strain. Thus, the strain is greatest at midships, and on each side of midships; and towards the ends as the vessel becomes finer, it gradually diminishes. Considerable as strains in still water may be under certain circumstances, on investigating the strains experienced at sea we shall see how enormously they are increased.

First, observe the strains endured by a ship in the condition shown in Fig. 22. Here the vessel is supported at midships on the summit of a wave, the extremities being practically unsupported. The ship may now be compared to a hollow girder with weights ranged miscellaneously throughout its length, and supported only at the centre, the result being a severe hogging strain tending to make the ends droop.



Figs. 22 and 23.—Strains of Vessels on Waves and in Troughs.

Distribution of Material to Resist Bending.—The question now arises, How should the material employed in the construction of the vessel be distributed so as to withstand this tendency to bend?

In Fig. 24, let A B be a bar of iron or steel 100 feet long, supported at the middle of its length, and with a weight of 10 tons attached to each end. This would not be an exact illustration of a loaded vessel supported at midships upon a wave as in Fig. 22, but it will form a fair approximation to the strains experienced by a vessel when in a light condition with large peak ballast tanks full, or it will show the evil of loading a vessel with the heaviest cargo at the ends, and will serve to illustrate the principle it is wished to make clear. Let the sectional area of the bar be the same throughout its length. The bending moment of each weight would be 10 × 50 = 500 foot-tons, and the tendency of the bar would be to bend or break at the point of support since the strain is greatest at this point. The tendency to break at 10 feet on each side of the support would be 10 × 40 = 400 foot-tons, and at 20 feet from the support 10 × 30 = 300 foot-tons and so on, the tendency to break diminishing towards the ends as the leverage decreases. The bending moment at any section from the centre to the end of the bar might be graphically illustrated in the following manner:—

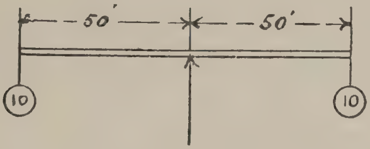


FIG. 24.—STRAIN ON A BAR LOADED AT EACH END.

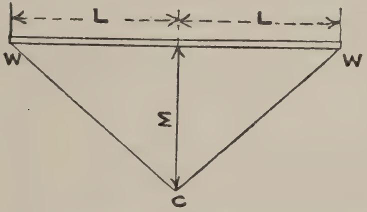


FIG. 25.—DISTRIBUTION OF BENDING MOMENT.

Let W = weight hung at each end of bar.
,, L = half length of bar (that is, length from centre to end of bar).
,, M = maximum bending moment (which occurs at centre of bar).

Make M equal weight multiplied by leverage—W × L = 10 × 50 = 500 foot-tons at the middle of the bar.
Join C W.

Let M be set off to any arbitrary scale; then by using the same scale the bending moment can be measured at any intermediate position between the support and the weight. In a similar manner the strains experienced by a vessel supported at the middle of her length upon a wave are greatest in the region of the half length amidships. The structural arrangements introduced, and the great value of such erections as long bridges over the middle of the length in affording strength to resist those bending strains, will be shown at a later stage.

Now, supposing the bar in Figs. 24 and 25 to be 4 square inches in sectional area, the question may be asked, Is it possible to arrange the material, preserving the same sectional area so as to get greater efficiency in resisting longitudinal bending? Let the bar be rolled out so as to make it 8 inches by ½ inch in section (same sectional area as previously), the length remaining the same. It will easily be seen that if the bar (or plate, as it now is) be supported as before with the wide 8-inch side horizontal, and the weights attached to its extremities, that it possesses less resistance to bending than when the bar was square in section.

But should the bar be supported with its wide 8-inch surface vertical, it will be found that its resistance to bending has been increased beyond what it was in the square section of the bar. Let us make a brief examination of this difference of resistance to bending with the same sectional area.

Let Fig. 26 represent the 8-inch by ½-inch plate, placed with the 8-inch side vertically, and let A B be the neutral axis. (The *neutral axis* is an imaginary line of no strain passing longitudinally through, say, the centre of depth of the plate. Since the plate is 8 inches deep, it will be 4 inches from each edge.) Supposing a weight be attached to each end of the plate, observe what must take place before it can bend. On the upper edge there must be considerable expansion or elongation, and on the lower, contraction or compression. The wider the plate is made, the greater will be the resistance to tensile strain on the upper edge, and compressive strain on the lower. It will also be found that the nearer the neutral axis is approached, the less elongation and compression are required to result in the same amount of bending, and at the neutral axis there is neither elongation nor compression.

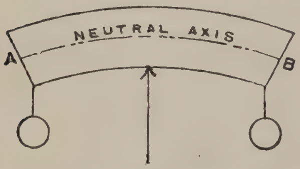


FIG. 26.—BENDING RESISTANCE OF BAR PLACED VERTICALLY.

Now, theory and experiment agree in showing that the stretching and compressive stresses at the top and bottom edges are now (8 inches by ½ inch wide side vertical), only one-fourth of what they were when the bar was square in shape (2 inches by 2 inches), and only one-sixteenth of what they are when the bar is 8 inches by ½ inch, but laid with its thin edge vertical (the formally stated law is that *the resistance of the bar to this kind of stress varies directly with the square of the depth of the bar, and directly as its breadth*).

The resistance to bending, moreover, will be greatly increased if the vertical plate be turned into a girder by attaching a bulb to its upper and lower edge, as shown by A in Fig. 27, or by adding strengthening flanges to the upper and lower edges, where the tensile and compressive strains are greatest, for example see Fig. 27, B, C, D, E, and F.

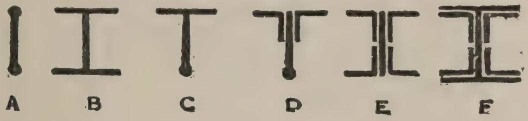


FIG. 27.—BENDING RESISTANCE OF GIRDERS.

Types of Vessels subject to Greatest Strain.—The principles which apply to a plate or girder apply equally well to a ship, for, after all, a ship is simply a huge, hollow girder, and from the foregoing reasoning the following deductions may be made:—

1st. That vessels of great length, and therefore subject to excessive bending moment among waves, require more longitudinal strength than short ones (not necessarily more transverse strength).

2nd. That long shallow vessels possessing less resistance to tensile and compressive strains require additional longitudinal strength.

3rd. That in all vessels more strength is required in the region of midships, and may be gradually reduced towards the ends.

Strains among Waves.—In studying the case of a ship in the condition shown by Fig. 23, it is observed that since the ends are supported on waves, and the midship part, containing engines, boilers, bunkers, &c., is to a large extent unsupported, the vessel, especially if a long one, will endure a severe sagging strain tending to make her droop amidships. There are cases on record where long, shallow vessels have actually fractured through the middle and sunk. The vessel may now be compared in some measure to a bar, supported at the ends with a weight in the centre, thus—

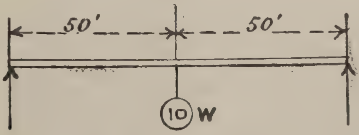


FIG. 28.—BAR WEIGHTED IN THE CENTRE.

and if the weight be, say, 10 tons, and its distance from each support 50 feet, then by the following diagram the bending moment may be illustrated :—

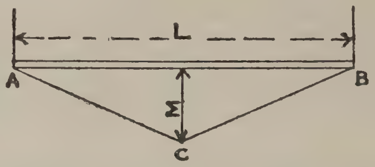


FIG. 29.—DISTRIBUTION OF BENDING MOMENT IN BAR.

Here, 10 tons in the middle gives 5 tons pressing on each support, and the bending moment in the middle (= pressure × leverage) = 5 tons × 50 feet = 250 foot-tons = M.

Set off M (250) to any scale, and join C B and C A. By using the same scale, the bending moments can be measured at any intermediate position between the support and the weight. Here again in this illustration it is shown that the longitudinal bending moment is greatest at the middle of the bar corresponding to the midship portion of the ship, decreasing towards the ends, where it vanishes altogether. This provides another reason why vessels should have greater longitudinal strength amidships than elsewhere.

Moreover, owing to the rapid transit of the waves, and, therefore, the unequal distribution of weight and buoyancy, the vessel is subject to a succession of severe and sudden strains. It will also be seen that in rolling among waves, there is a great tendency for a vessel to alter in transverse form. Under such circumstances she may be compared to a box, as shown in Fig. 30.

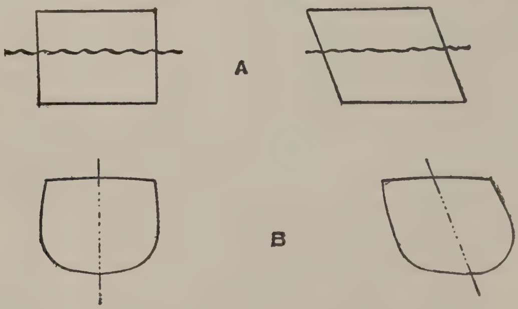


FIG. 30.—STRAINS DUE TO ROLLING AMONG WAVES.

If a series of irregular collapsing strains be put upon the exterior of the box, the tendency is not so much to fracture in the positions shown by the wavy lines, but to work at the corners. Exactly the same thing takes place with a ship at sea as she rolls among the waves. The strain tends to have the effect shown in B, Fig. 30.

Thus in determining the size and arrangement of all material in the construction of ships, there must be sufficient longitudinal strength to resist all longitudinal bending forces, and sufficient transverse strength to resist all collapsing forces or alteration to transverse form of the nature already described, with a reasonable margin for safety.

As has been already shown, it is not necessary to have as much sectional area of material towards the ends of the vessel, as near amidships, since the strain is less; but, nevertheless, in comparison with the strain which has to be borne, both sections should be equally able to withstand such strains as come upon them, for it should be remembered that the vessel is no stronger than her weakest part.

Thus far, only strains affecting the ship as a whole have been considered, but there are several other strains it is necessary to take into account which only affect the vessel locally.

1. *Panting Strains.*—The fore end of the vessel, especially when of a bluff form of stem and driven at a high speed, being the first part to pass through the water, naturally suffers great head resistance, tending to make this part pant or work in and out.

2. *Strains due to Propulsion by Steam.*—These strains may be divided into (1) strains owing to weight of engines and boilers, and (2) strains due to vibration of shaft, &c.

3. *Strains due to Propulsion by Sail.*—In vessels with lofty masts and much sail area, great strain is transmitted to the hull through the masts by the force of the wind and the action of rolling.

4. *Strains owing to heavy permanent weights carried*, such as winches, windlass, cranes, anchors, guns, &c.

5. *Strains from Deck Cargoes.*—It is customary with many vessels, such as those engaged in the "Baltic" trades, to carry coal or some other British export on the outward voyage, and to return with cargoes of timber, and in order to get the vessel down to her load waterline large deck cargoes are carried. Many of the shipmasters engaged in such trades are not unacquainted with the fact that owing to the heavy deck weight these vessels are severely strained, and sometimes take a set or sort of twist, and this is only discovered after the cargo has

been removed, and perhaps not until even a few days later still, when the vessel, sometimes with a considerable report, frees herself from her strained condition with a severe trembling from stem to stern. On examination it is found that very many of the rivets in the heads of the hold stanchions or pillars have been sheered, and considerable damage done to the beam knees. This is an abundant proof that vessels intended to carry heavy deck cargoes require special strengthening.

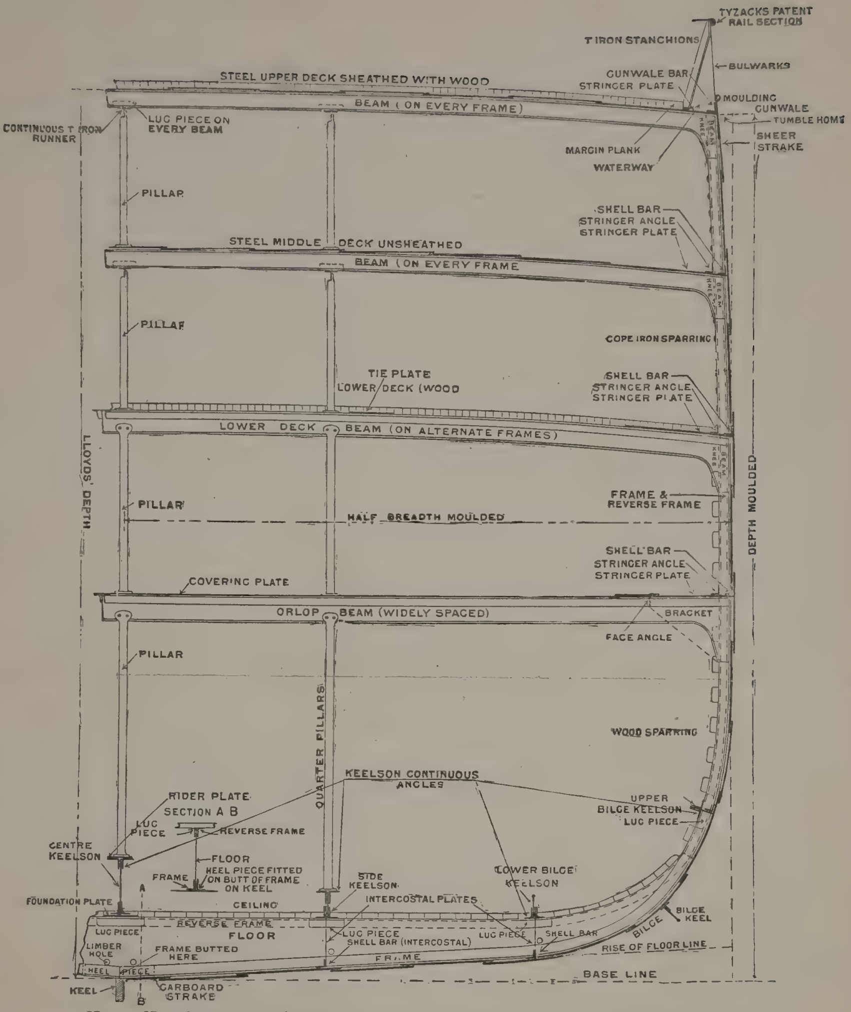
Such damage as that just explained might often be obviated by wedging or shoring the space between the top of the hold cargo and the beams, thus assisting the beams in enduring the strain of the deck cargo.

6. *Strains from the shipping of seas* against poop or bridge fronts. Bridge and poop fronts with closed ends are subject to sudden and severe strains owing to the shipping of heavy seas, which will evidently spend their force against these bulkheads. Such parts, therefore, require special attention, and it is only possible to secure the maximum allowance on the freeboard when these parts are most efficiently constructed.

7. *Strains from Loading Cargoes Aground.*—Vessels engaged in trades where it is known that they will lie aground during the operation of loading and unloading, require special stiffening on the bottom. And so on, cases might be enumerated where, special strain having to be endured, special strengthening must be provided.

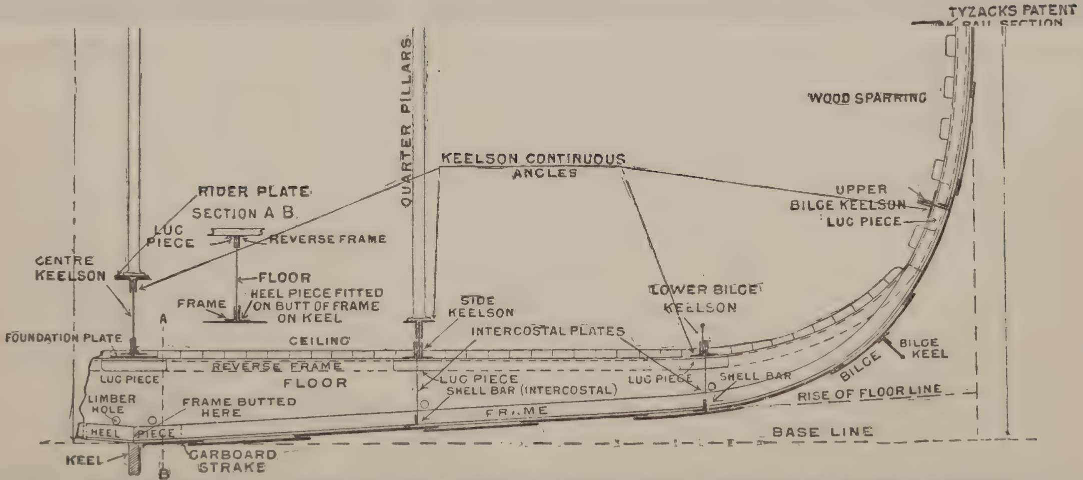
Excessive strains, such as those borne by a vessel when run ashore, as frequently happens, so that one end only is waterborne, or where the vessel, possibly laden with a heavy cargo, is laid across a sandbank, with ends unsupported when the tide has left her, the shipbuilder cannot attempt to cover, but all strains, such as those already mentioned, may be thoroughly provided against.

A vessel in dry dock, unless carefully shored, may be considerably damaged. Cases of dry docking where the bilges have drooped have occurred through carelessness or ignorance. Having briefly enumerated the chief strains borne by a vessel under various circumstances, the reader will now be better prepared to understand why exceptional strength is introduced into the structure, either considered as a whole, or in particular parts only.



NOTE.—No reduction is obtained in the thickness of a steel or iron deck by sheathing it with wood.

FIG. 31.—MIDSHIP SECTION OF MERCHANT STEAMER.



NOTE.—No reduction is obtained in the thickness of a steel or iron deck by sheathing it with wood.

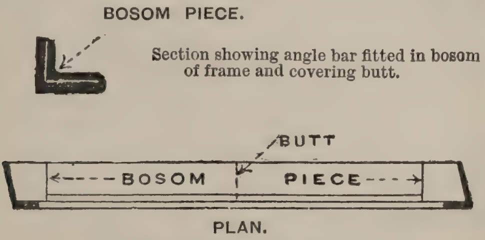
FIG. 31.—MIDSHIP SECTION OF MERCHANT STEAMER.

CHAPTER V.

STRUCTURE.

Contents.—Parts of Transverse Framing, and How Combined and United to Produce Greatest Resistance to Alteration in Form—Sections of Material Used—Compensation for Dispensing with Hold Beams—Parts of Longitudinal Framing, How Combined and United to Transverse Framing to Produce Greatest Resistance to all Kinds of Longitudinal Bending and Twisting—Forms of Keels and Centre Keelsons, and their Efficiency—Distribution of Material to Counteract Strain—Value of Efficiently-Worked Shell and Deck Plating in Strengthening Ship Girder—Definitions of Important Terms—Illustration of Growth of Structural Strength, with Increase of Dimensions by means of Progressive Midship Sections—Special Strengthening in Machinery Space—Methods of Supporting Aft End of Shafts in Twin-Screw Steamers—Arrangements to Prevent Panting—Special Strengthening for Deck Cargoes and Permanent Deck Weights, and also to Counteract Strains due to Propulsion by Wind—Types of Vessels—Comparison of Scantlings of a Three-Decked, a Spar-Decked, and an Awning-Decked Vessel—Bulkheads—Rivets and Rivetting.

Transverse Framing.—The parts of the structure of a ship affording resistance to transverse strains, according to the usual mode of construction, are included in the combination known as *transverse framing*. A complete transverse frame comprises a *frame bar*, a *reverse bar*, a *floor plate*, a *beam*, and a *pillar*, efficiently united. According to the size of the vessel, the spacing of the transverse frames varies from about 20 to 26 inches from stem to stern. Let us take for our example an ordinary merchant steamer, a midship section of which is shown in Fig. 31.



Section showing angle bar fitted in bosom of frame and covering butt.

Fig. 32.—Angle Bar.

The *frame bar* extends continuously from keel to gunwale in this type of vessel. Should there, from any cause, be a break in the length of the frame, the strength should be preserved by lapping the parts to make the connection, or by fitting angle butt straps, or other efficient means of compensation should be adopted (see Fig. 32, and section A B in Fig. 31). This indeed is a rule which should be rigorously observed throughout the construction of a ship, that *wherever a structural part is weakened, the strength be fully recovered by compensation in some form or other.* If the frames meet or butt on the keel, as they usually do, they are connected by pieces of angle bar about 3 feet long, fitted back to back, which, in addition, provide a substantial means of connection to the shell plating. The usual form of frame is the plain angle bar (see A, Fig. 33).

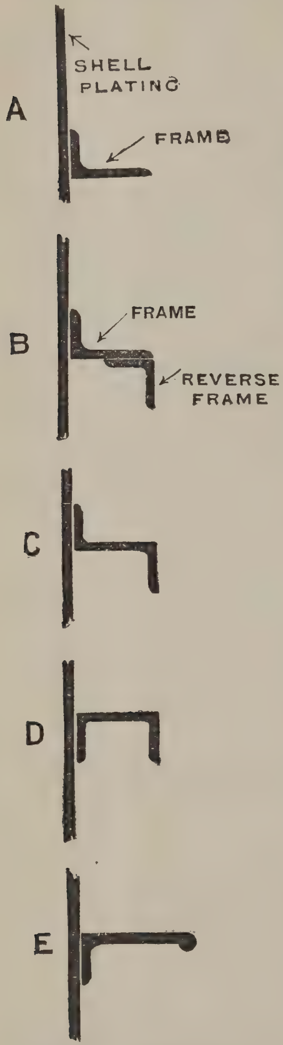


Fig. 33.—Frame Bars.

It will be noticed that one flange of the bar is longer than the other, the long flange always points into the interior of the ship, and the short one is attached to the shell plating. Since the greater the girth of the vessel, and thus the greater the collapsing strain, it is evident that the vessel needs more transverse strength in the region of midships, where it is fullest, than towards the ends. It is, therefore, usual to make the frames one-twentieth of an inch thicker for three-fifths of the length at amidships than at the ends. The frame bar is made stronger and more rigid, and, therefore, the better able to keep out the ship's side by means of a *reverse bar*, which is similar in section, but smaller in size. It is rivetted to the back of the frame (see B, Fig. 33), and being on the side of the frame hidden from view in Fig. 31, it is there shown in dotted lines. The reverse bar does not always extend to the same height as the frame. As will be seen further on, its height is governed by the transverse dimensions of the vessel, for the greater the girth and beam, the greater the need for transverse strength. Across the bottom of the ship, and extending well up the bilge, is a deep plate called a *floor plate.* On the lower edge of this plate is attached the large flange of the frame bar, and across the other side on the upper edge is bent and rivetted the reverse angle after it leaves the frame (see section A B, Fig. 31). The floor plate, being now converted into a girder, affords great stiffness and strength to the bottom of the ship.

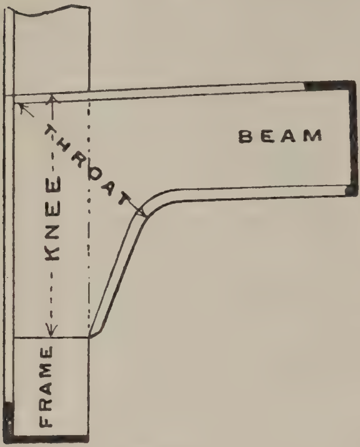
Instead of the usual frame and reverse frame there are other sections of bar iron or steel which may be used. For example, there is the Z-bar (see C, Fig. 33), which is a combination of the frame and reverse frame rolled in one section, thus saving the necessity of rivetting these two together. It is very strong, and is extensively used in the building of ships for the Royal Navy.

A very similar bar to this, sometimes used for framing large vessels, is the channel iron section shown in D, Fig. 33.

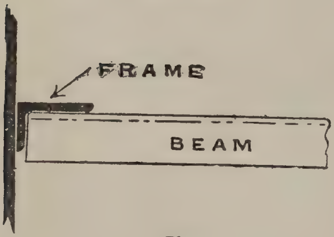
This also saves the rivetting of a reverse bar. When this section is used, it is generally dispensed with towards the ends of the vessel, and the ordinary frame and reverse angle bar substituted, as it is difficult to bend and bevel the channel bars as required at the ends of the vessel. There is also the bulb angle section (see E, Fig. 33.)

This is sometimes adopted in vessels where no sparring is required in the holds, thus permitting some kinds of cargo to be trimmed right against the shell, an advantage being gained in cubic capacity. By this means also the reverse bar may be dispensed with when the bulb angle is made strong enough to equal the frame and reverse bars together.

Another important part of transverse framing is the *beams*, uniting, as they do, the upper extremities of the frame bars and holding them in position, thus forming the foundation for decks. In addition, they complete the transverse section of the hollow girder into which we have resolved our ship. It would be useless to secure sufficient structural strength in the various bars forming the transverse skeleton of a vessel, unless at the same time every attention were given to the efficient connection of these parts to one another. We have already noticed how the frame butts are strengthened and connected, but there is still the connection of the frame and the beams. This is done by welding or rivetting to each extremity of the beam a *knee plate* (Fig. 34.), which is fitted into the bosom of the frame.



Elevation.



Plan.

Fig. 34.—Beam Knee.

The British Corporation recognises the necessity of an efficient connection at this part, by compelling all ships built under its survey to have knees, three times the depth of the beam, and one-and-three-quarters the depth at the throat, to all beams in the way of the main deck. Lloyd's require the depth of the knee to be two-and-a-half times the depth of the beam, and one-and-a-half times the depth of the beam at the throat for steam vessels, while for sailing ships over 36 feet broad the knees must be three times the depth of the beam.

Like frame bars, the beams may vary in sectional form. Under iron or steel decks it is usual and better to fit angle or angle bulb beams to every frame, and under wood decks, on alternate frames, beams of the following sections may be adopted :—

(1) Butterly Bulb (see A, Fig. 35).

(2) Bulb Plate, and double angles rivetted to its upper edge (see B, Fig. 35). Or,

(3) Channel Bar (see D, Fig. 33).

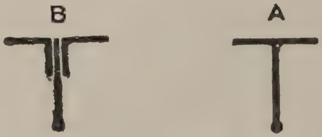


Fig. 35.—Beams.

Compensation for Dispensing with Hold Beams.—However, these may be considerably modified according to the length of the beams, since the length of the beams determines the size of bar to be used. Vessels may have two, three, four, or more tiers of beams, according to their depth. Now, let us suppose a shipowner is about to have a vessel built with a depth of 16 feet. He finds, if he intends to class the vessel at Lloyd's, that she requires hold beams fastened to every tenth frame, and at the extremities of the beams a stringer plate (see Fig. 31) securely attached to beams and shell. But as these would interfere with the stowage of cargo he intends to carry, let us see what alternative he may adopt in order to dispense with the hold beams. If he wishes, he may fit transverse web

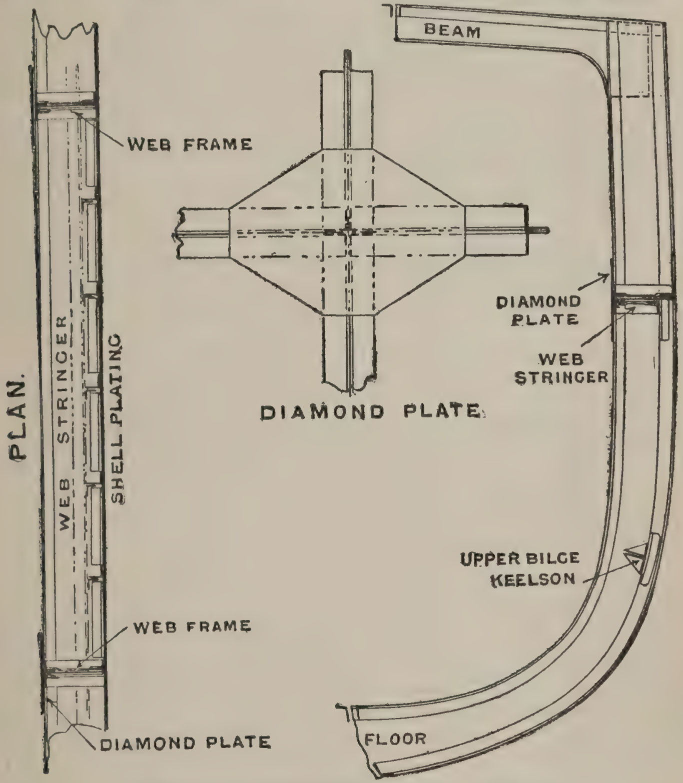


FIG. 36.—SUBSTITUTES FOR HOLD BEAMS.

frames (see Fig. 36) at distances of eight frame spaces apart all fore and aft; this compensates for loss of beams.

In addition, there must be fitted a longitudinal web frame, or web stringer as it is called, all fore and aft, between the transverse web frames, and securely attached to them by angles on the upper and the lower sides, and also by means of an efficient diamond plate on its front edge. This compensates for the loss of the stringer plate on hold beams. The next thing to be done is to have the upper extremities of the web frames firmly tied together and held in position. This is done by fitting extra strong beams across the vessel, attached to the web frames by extra strong deep knees. Since the function of the beam and stringer plate is to tie and stiffen the sides of the ship, the web frame being a transverse plate girder, and the web stringer a longitudinal plate girder, the one firmly united to the other enables them to do their work together, and thus serve the same purpose. It will be observed that the web frame shown in Fig. 36 is a continuation of the floor plate, and also that both it and the web stringer are stiffened by double angles on their inner edges.

Another alternative is to stiffen the ship at every frame space all fore and aft, by fitting two large angles back to back (Fig. 37). This method makes a substitute for both hold beams and reverse frames.

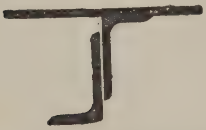


Fig. 37.—Substitute for Hold Beams and Reverse Frames.

There is still another part in the transverse framing to be noticed—namely, the *pillars*. They are rivetted to the beams, and usually to the girder on the top of the floors, or some other part of the bottom of the vessel. They bind the upper and lower parts of the structure together, and perform the function of a strut and a tie by holding the beams and the bottom of the ship in their right positions relatively to each other; and thus by uniting the two great horizontal flanges of the ship girder, the deck and the bottom, they enable them to act in unison in resisting longitudinal strains.

When considering the subject of strains, we noticed that in rolling among waves a vessel has the tendency to alter her transverse form, and to work at the corners. After observing the combination constituting transverse framing, we shall now be able to see how these parts unite in offering resistance to the alteration of transverse form.

1. *At the Bilge Corners.*—Here we have the floor plate curved up the bilge to a height of twice its depth at the middle line of

the vessel, thereby supporting the bilge in the form of a web at every frame.

2. *At the Deck Corners.*—In this case we see the efficiency developed by the deep beam knees in giving support in the form of webs at every beam.

3. Furthermore, there is the great assistance provided in the form of the beams themselves holding the sides of the vessel rigid, the beams being in their turn supported by the pillars.

Longitudinal Framing.—The longitudinal framework of the vessel is made up of the *keel*, *keelsons*, and *stringers*. These may partake of a variety of forms, with a few of which we shall briefly deal, together with the means adopted for binding them all together in order to secure an efficient and strong framework. The number of keelsons and stringers depends upon the size and proportions of the vessel.

Keel.—The keel shown in Fig. 31 is known as the ordinary bar keel. It is made up of long lengths of bar iron connected by means of scarphs, the length of which should be sufficient to secure a good connection (see Fig. 38). If the vessel be classed at Lloyd's, the scarphs will be nine times the thickness of the keel, and if with the British Corporation, three times the depth of keel.

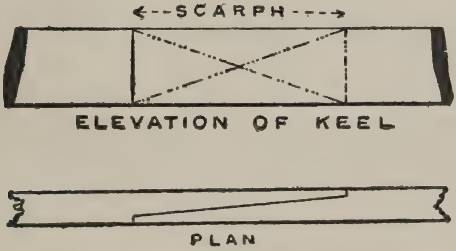


Fig. 38.—Keel.

The same method of connection unites the keel to the stem and the stern posts. These connections may also be made by welding, but this is seldom done.

A superior arrangement of this kind of keel is the one known as the side bar keel (see E, Fig. 39).

It consists of a deep plate extending down from above the top of the floors to the bottom of the keel, the thickness of the keel part being made up by attaching two side bars or slabs of iron, one on each side of the lower extremity of the centre plate. The whole is then rivetted to the two strakes of shell plating which cover the keel, and are called the *garboard strakes* (see Fig. 31). A thoroughly strong result is thus secured. Holes are cut in the centre plate at the top of the keel to allow the *heel piece*, or frame back bar, as it is sometimes called, to be fixed in position. The butts or connections of these plates comprising the keel must be kept well clear of each other, and separated by at least two frame spaces, wherever practicable.

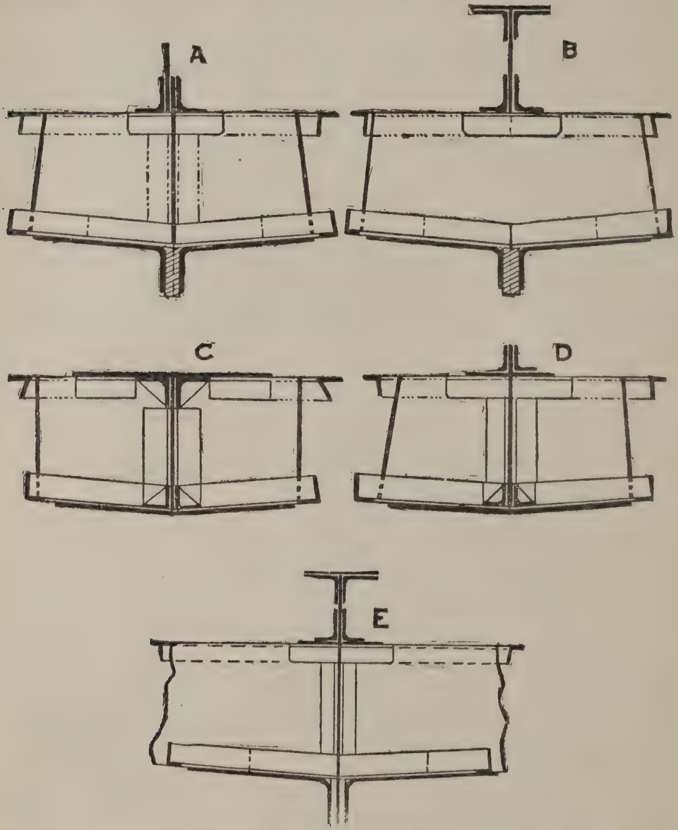


Fig. 39.—Keels and Keelsons of Various Forms.

The centre plate being carried up above the top of the floors forms part of the centre keelson. Two horizontal plates are then attached to the floor plates, one on each side of the centre plate, the connection being made by means of the reverse angles. To the upper edge of the centre keelson plate two angles are rivetted, and also two others on the top of the horizontal plates. The combination now forms a splendid backbone to the whole ship. It will be noticed in Fig. 31, as also in A, B, C, D, and E, Fig. 39, that a short piece of angle bar called a *lug piece* is attached to the top of the floors on the opposite side to the reverse angle, thereby ensuring a doubly strong connection between the keelson and the transverse framing, for unless the longitudinal and transverse framings are thoroughly united, their separate strength is of little value to the ship as a whole, and they would thus fail in their chief function.

Keelsons.—The commonest form of centre keelson consists of a single plate standing upon the top of the floors with double angles rivetted to its upper and lower edges, as shown in B, Fig. 39. In addition, a plate called a *rider plate* is rivetted on the top of the two uppermost angles. The great disadvantage of this keelson, especially in large heavy vessels, is, that it affords no resistance whatever to buckling of the floors, and thus it has often happened that when vessels of this form of construction have grounded upon an uneven bottom, the keel has been sprung up, and consequently the floors having nothing between them to stiffen them vertically at their deepest part, have buckled. This lack of stiffening between floors is the great defect of all keelsons standing simply upon the top of the floors.

A very good kind of centre keelson is that shown in A, Fig. 39. Here we have the deficiency in the previous keelson remedied. Its parts are as follows:—First, there is the deep bulb plate, with angles on its lower edge, attached to the top of the floors. Between one of the angles and the bulb plate an intercostal plate is let down between all the floors on to the top of the keel, and secured to the floors by vertical angle bars, as shown.

A now unfamiliar, though very efficient, form of centre keelson is sometimes to be seen in old vessels. A sketch of the same is shown in C, Fig. 39. It consists of a continuous centre plate extending from the top of the floors to the top of the keel, the latter being a broad thick plate known as a flat-plate keel. On the top of the floors a thick broad plate is laid, and attached to the vertical keelson plate by large double continuous angles, as shown. Since the entire centre keelson is continuous, it follows that the floor plates must butt on either side of it, the connections between the two being made by double angles. The vertical plates comprising the centre keelson are connected by double butt straps (see Fig. 69) treble rivetted. The horizontal plate is also rivetted to the reverse angles on the top of the floors, and in addition to a short lug piece fitted on the top edge of the floor opposite to the reverse bar. This form of centre keelson is usually adopted in double bottoms (see Fig. 51).

In D, Fig. 39, we have another modification of a centre keelson with a flat plate keel. The centre plate is continuous, and extends above the top of the floors sufficiently high to take two large angle bars which are rivetted to two horizontal plates shown on each side of the centre plate, and also to the top of the floors.

Keelsons and stringers are fitted for the purpose of giving longitudinal stiffness to the vessel, and also in order to tie or unite the transverse framing, so that when strain is brought to bear upon any particular part, it is transmitted to the structure as a whole.

Keelsons and stringers are all forms of girders (see Fig. 31), varying both in number and size, according to the dimensions and structural requirements of the vessel.

Those longitudinal stiffeners located along the bottom of the vessel between bilge and bilge are called *keelsons*, above the bilge they are termed *stringers*.

Stringers.—It will be noticed that wherever a tier of beams is fitted in a vessel, a broad thick plate, called a stringer plate, is attached to its extremities, and connected with the shell by a strong angle bar. This bar, called a *shell bar*, is fitted intercostally between the frames if below the weather deck, and to the reverse frames extending above the beams a continuous angle bar is rivetted, and also to the stringer plate. If the deck is an iron or steel one, the plate at the end of the beams is still called a stringer plate. It is always thicker than the adjoining plating, and, being firmly connected with the beams and shell, it forms a splendid longitudinal stiffener to the vessel, acting in conjunction with the beams and transverse framing in keeping out the sides of the vessel to their proper position and shape, and in resisting longitudinal twisting strains.

If the beams are widely spaced and no deck is laid, the stringer plate is supported by means of knees or bracket plates underneath.

We observed at the beginning of this chapter that not only is the transverse strain greatest, but the longitudinal also, in the region of amidships, and is gradually reduced towards the ends of the vessel, thus showing that a reduction may be made in the thickness of the material used in the construction towards the ends. This applies generally throughout the vessel, for, be it remembered, excessive strength is useless.

Distribution of Material to Counteract Strain.—With such an able means of conveying instruction to our minds as the eye, it seems very probable that, with short explanatory notes, a few sketches, showing both the arrangement and growth of the framing and plating, ranging from the smallest to large types of merchant vessels, will prove of more value, and will be plainer than perhaps pages of printed matter. Before doing this we must not omit to notice that although the first aim is to secure the greatest possible efficiency out of a good combination of longitudinal and transverse framing, yet immense strength is added by an efficiently worked skin, or *shell plating*, as it is more commonly termed. Some parts of this outside plating are capable of rendering more service to the structure than others.

For example, the ordinary bar, or *hanging keel*, as it is often termed, has its only connection to the vessel by means of the strakes, or rows of plating, called the garboard strakes, on either side of the keel. The absurdity of connecting a thin plate to a thick bar with large rivets, widely spaced, will be easily understood, and thus the garboard strake is made thicker than its adjacent plating. Moreover, where no heel pieces are fitted, connecting the lower extremities or heels of the frames on one side of the vessel to those on the other side, the garboard strakes accomplish this by securing the heels of the frames firmly to the top of the keel. It also adds stiffness to the bottom flange of the ship girder.

We have already seen the advantage of strengthening the upper and lower edges or flanges of a girder in increasing its efficiency to resist longitudinal bending, and since a ship, as previously stated, is simply a huge hollow girder, any method of deepening it vertically (ship's side plating, &c.), or increasing the strength of its upper and lower flanges, must add to its longitudinal strength. Hence it is compulsory if a vessel be classed to have its uppermost strake of outside plating, called the *sheer strake*, and sometimes the strake next below, increased considerably in thickness (see Fig. 31). Also on the bottom of the girder, in the region of the bilge, one or two of the strakes are thickened in long vessels. Midway between the bilge and the sheer strake—approximately in the region of the neutral axis—where the strains vanish, the thickness of the plating is least. The value of long bridges extending over the midship length of a vessel, increasing the depth of the girder at the very place where the bending strain is greatest, must be evident. Indeed, in two- and three-decked vessels of over thirteen depths to length, Lloyd's require that they have a substantial erection extending over the midship half length. A complete or partial steel deck over the middle of the length, together with the beams, also affords great strength to the ship girder in increasing the efficiency of its upper flange.

Definition of Important Terms.—It is necessary at this stage that a few terms be clearly understood.

1. *Length between Perpendiculars.*—For vessels with straight stem this is taken from the fore part of the stem to the after part of the stern post. Should the vessel have a clipper or curved stem, the length is measured from the place where the line of the upper deck beams would intersect the fore edge of the stem, if it were produced in the same direction as the part below the cutwater (Fig. 40).

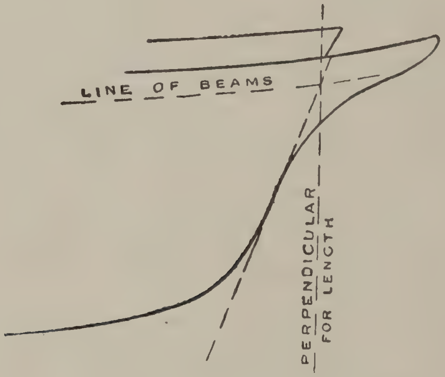


FIG. 40.—LENGTH BETWEEN PERPENDICULARS.

2. "*Lloyd's Length.*"—Lloyd's length is the same as the foregoing, except that the length is taken from the after side of the stem to the fore side of the stern post.

3. *Extreme Breadth.*—This is measured over the outside plating at the greatest breadth of the vessel.

4. *Breadth Moulded.*—This is taken over the frames at the greatest breadth of the vessel.

5. *Depth Moulded.*—This is measured in one-, two-, and three-deck vessels at the middle of the length from the top of the keel to the top of the upper deck beams at the side of the vessel.

In spar- and awning-decked vessels, the depth moulded is measured from the top of the keel to the top of the main deck beams at the side of the vessel.

6. *Lloyd's Depth.*—This is somewhat different. We have seen that they require a round up upon the weather decks, of a

quarter of an inch to one foot of beam. This round up is added to the moulded depth, and gives Lloyd's depth. With this modification it is otherwise the same as No. 5.

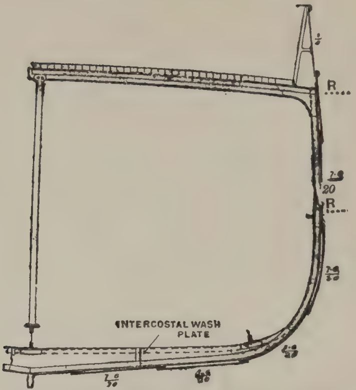
In designing our series of midship sections illustrating the arrangement, amount, and development in structural strength in progressive sizes of vessels, we will consider, for the sake of example, that the vessels are to be classed at Lloyd's.

The size and spacing of all transverse framing—frames, reverse frames, floor plates, pillars—are regulated by numbers obtained entirely from transverse dimensions, as follows :—

Add together (measurements being taken in feet) *half the moulded breadth, the depth (Lloyd's), and the girth of the half midship frame section of the vessel, measured from the centre line at the top of the keel to the upper deck stringer plate.* By referring to the tables in Lloyd's Rules, the sizes of these parts of the structure, corresponding to the sum of these dimensions, may be found. The number for three-deck steam vessels is produced by the *deduction of 7 feet from the sum of the measurements taken to the top of the upper deck beams.*

The sizes of all longitudinal framing—keel, keelsons, stringers, as well as thickness of outside and deck plating, stem bar, and stern frame—are governed by the number obtained by *multiplying Lloyd's first number for frames, &c., by the length of the vessel.*

Vessels of extreme dimensions require special stiffening above that ordinarily needed by the numbers obtained as above, and special provision is made for this in the rules.



Under 13 feet depth. 12½ depths in length.

FIG. 41.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN 13 FEET IN DEPTH.

Lloyd's Numerals.

½ Girth,	21·8
½ Breadth,	12·0
Depth,	12·83
1st No.,	46·63
Length,	161
2nd No.,	7507

Frames, $3 \times 3 \times \frac{6-5}{20}$, spaced 21 ins.

Reverse frames, $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{20}$.

Floors, $13 \times \frac{6-5}{20}$.

Centre keelson, $11 \times \frac{9-7}{20}$.

Keelson continuous angles, $3\frac{1}{2} \times 3 \times \frac{6}{20}$.

Beams, $5\frac{1}{2} \times \frac{5}{20}$ – bulb plate with Double angles, $2\frac{1}{2} \times 2\frac{1}{4} \times \frac{5}{20}$.

Sheer strake, $32 \times \frac{11-8}{20}$.

Garboard strake, $31 \times \frac{9-8}{20}$.

Stringer plate, $36 \times \frac{8}{20} - 19 \times \frac{6}{20}$.

Gunwale angle bar, $3 \times 3 \times \frac{7}{20}$.

Keel, $7 \times 1\frac{5}{8}$.

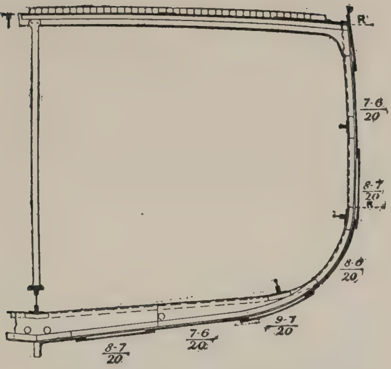
Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for ¾ L amidships.
To bilge keelson, a bulb plate is added for ⅗ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added for ½ L amidships.

Abbreviations.

L means length, thus
¾ L amidships ,, three-fourths length amidships.
R ,, reserve frame height.
$\frac{8-7}{20}$,, thickness reduced from $\frac{8}{20}$ to $\frac{7}{20}$.

Note.—All sizes of plates and angle bars are given in inches.



Under 14 feet depth. 12½ depths in length.

FIG. 42.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN 14 FEET IN DEPTH.

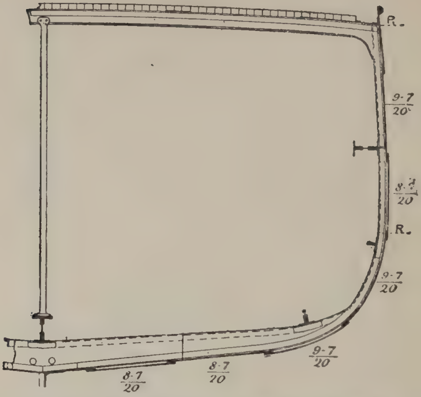
Lloyd's Numerals.

½ Girth, ...	24
½ Breadth, ...	13·5
Depth, ...	13·83
1st No., ...	51·33
Length, ...	173
2nd No., ...	8880

Frames, 3 × 3 × $\frac{6-5}{20}$, spaced 21 inches.
Reverse frames, 2½ × 2½ × $\frac{5}{20}$.
Floors, 14½ × $\frac{6-5}{20}$.
Centre keelson, 12 × $\frac{9-7}{20}$.
Keelson continuous angles, 3½ × 3 × $\frac{6}{20}$.
Beams, 6½ × $\frac{6}{20}$ – bulb plate with } on alternate frames.
Double angles, 2½ × 2½ × $\frac{6}{20}$ }
Hold pillars, 2½.
Sheer strake, 33 × $\frac{12-8}{20}$.
Garboard strake, 32 × $\frac{9-8}{20}$.
Deck stringer plate, 38 × $\frac{8}{20}$ – 20 × $\frac{6}{20}$.
Gunwale angle bar, 3 × 3 × $\frac{7}{20}$.
Keel, 7¼ × 1⅞.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for ¾ L amidships.
To bilge keelson, a bulb plate is added for ⅗ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added for ½ L amidships.



Under $15\frac{1}{2}$ feet depth. $12\frac{1}{2}$ depths in length.

FIG. 43.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN $15\frac{1}{2}$ FEET IN DEPTH.

Lloyd's Numerals.

½ Girth, ...	26·5
½ Breadth, ...	14·5
Depth, ...	15·33
1st No., ...	56·33
Length, ...	192
2nd No., ...	10815

Frames, $3\frac{1}{2} \times 3 \times \frac{6-5}{20}$, spaced 22 inches.

Reverse frames, $3 \times 2\frac{1}{2} \times \frac{5}{20}$.

Floors, $16 \times \frac{7-6}{20}$.

Centre keelson, $12 \times \frac{10-8}{20}$.

Keelson continuous angles, $4\frac{1}{2} \times 3 \times \frac{7}{20}$.
Hold pillars, $2\frac{5}{8}$.
Beams, $7 \times \frac{7}{20}$ – bulb plate with } on alternate frames.
Double angles, $3 \times 3 \times \frac{6}{20}$ }

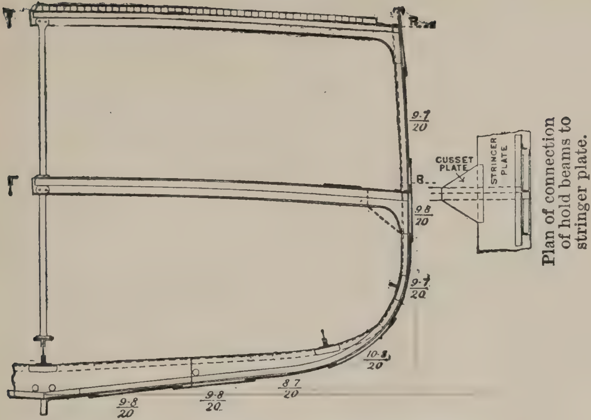
Sheer strake, $34 \times \frac{12-8}{20}$.

Garboard strake, $32 \times \frac{9-8}{20}$.

Deck stringer plate, $40 \times \frac{9}{20} - 22 \times \frac{7}{20}$.
Gunwale angle bar, $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{20}$.
Keel, $7\frac{1}{2} \times 2$.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for $\frac{3}{4}$ L amidships.
To strake below sheer strake, $\frac{1}{20}$ is added for $\frac{1}{2}$ L amidships.
To bilge keelson, a bulb plate is added for $\frac{3}{5}$ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added for $\frac{1}{2}$ L amidships.



Under 16½ feet depth. 12½ depths in length.

FIG. 44.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN 16½ FEET IN DEPTH.

Lloyd's Numerals.

½ Girth,	28·3
½ Breadth,	15·5
Depth,	16·33
1st No.,	60·13
Length,	205
2nd No.,	12326

Frames, $3\frac{1}{2} \times 3 \times \frac{7-6}{20}$, spaced 22 inches.

Reverse frames, $3 \times 2\frac{1}{2} \times \frac{6}{20}$.

Floors, $17\frac{1}{2} \times \frac{8-7}{20}$.

Centre keelson, $13 \times \frac{10-8}{20}$.

Keelson continuous angles, $4\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{20}$.

Main deck beams, $7\frac{1}{2} \times \frac{7}{20}$, bulb plate with
Double angles, $3 \times 3 \times \frac{6}{20}$ } on alternate frames.

Hold beams, $8\frac{1}{2} \times \frac{8}{20}$, bulb plate with
Double angles, $4 \times 3 \times \frac{7}{20}$, with covering plate } on every 10th frame.

Main deck stringer plate, $44 \times \frac{9}{20} - 24 \times \frac{7}{20}$.

Hold stringer plate, $27 \times \frac{7}{20} - 21 \times \frac{6}{20}$.

Gunwale angle bar, $4 \times 4 \times \frac{7}{20}$.

Sheer strake, $35 \times \frac{12-8}{20}$.

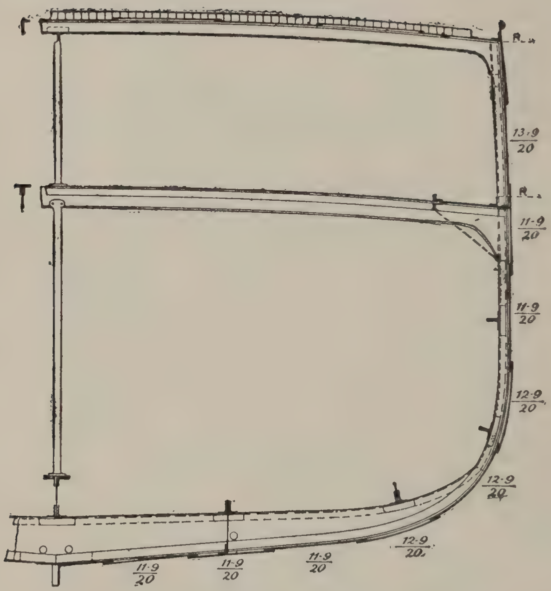
Garboard strake, $33 \times \frac{10-9}{20}$.

Keel, $7\frac{1}{2} \times 2\frac{1}{4}$.

Hold pillars, $2\frac{3}{4}$.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for ¾ L amidships.
To strake below sheer strake, $\frac{1}{20}$ is added for ½ L amidships.
To bilge keelson, a bulb plate is added for ⅗ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added for ½ L amidships.



Under 23 feet depth. 12½ depths in length.

FIG. 45.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN 23 FEET IN DEPTH.

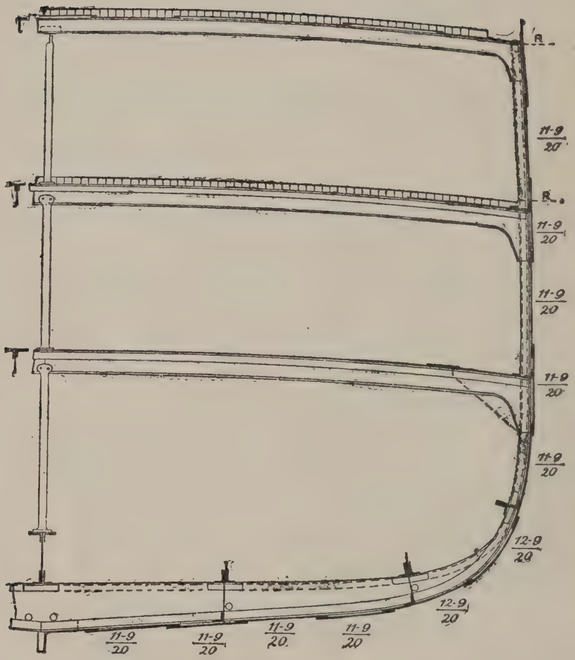
Lloyd's Numerals.

½ Girth,	38
½ Breadth,	19
Depth,	22·83
1st No.,	79·83
Length,	286
2nd No.,	22831

Frames, 5 × 3 × $\frac{8-7}{20}$, spaced 24 inches.
Reverse frames, 3½ × 3 × $\frac{8}{20}$.
Floors, 24 × $\frac{10-8}{20}$.
Centre keelson, 20 × $\frac{13-11}{20}$.
Keelson continuous angles, 6 × 4 × $\frac{9}{20}$.
Intercostal keelson plate, $\frac{8}{20}$.
Complete steel deck, $\frac{7}{20}$ thick on main deck.
Main deck beams, 6½ × 3 × $\frac{9-8}{20}$, bulb angle on every frame.
Hold beams, 10½ × $\frac{10}{20}$ bulb plate, with
Double angles, 4½ × 4 × $\frac{9}{20}$ } on every 10th frame.
Main deck stringer plate, 41 × $\frac{10}{20}$ – 35 × $\frac{8}{20}$.
Hold stringer plate, 38 × $\frac{9}{20}$ – 29 × $\frac{8}{20}$.
Gunwale angle bar, 4½ × 4½ × $\frac{10}{20}$.
Sheer strake, 42 × $\frac{15-10}{20}$.
Garboard strake, 36 × $\frac{12-11}{20}$.
Keel, 10 × 2½.
Hold pillars, 3½.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for ¾ L amidships.
To strake below sheer strake, $\frac{2}{20}$ is added for ½ L amidships.
To bilge keelson, a bulb plate is added for ⅗ L amidships.
To thickness of 3 strakes at bilge, $\frac{1}{20}$ is added for ½ L amidships.



Under 26 feet depth.
16 depths to middle deck in length.
11·6 ,, upper ,,

FIG. 46.—DIMENSIONS OF FRAMEWORK AND PLATING FOR VESSELS LESS THAN 26 FEET IN DEPTH.

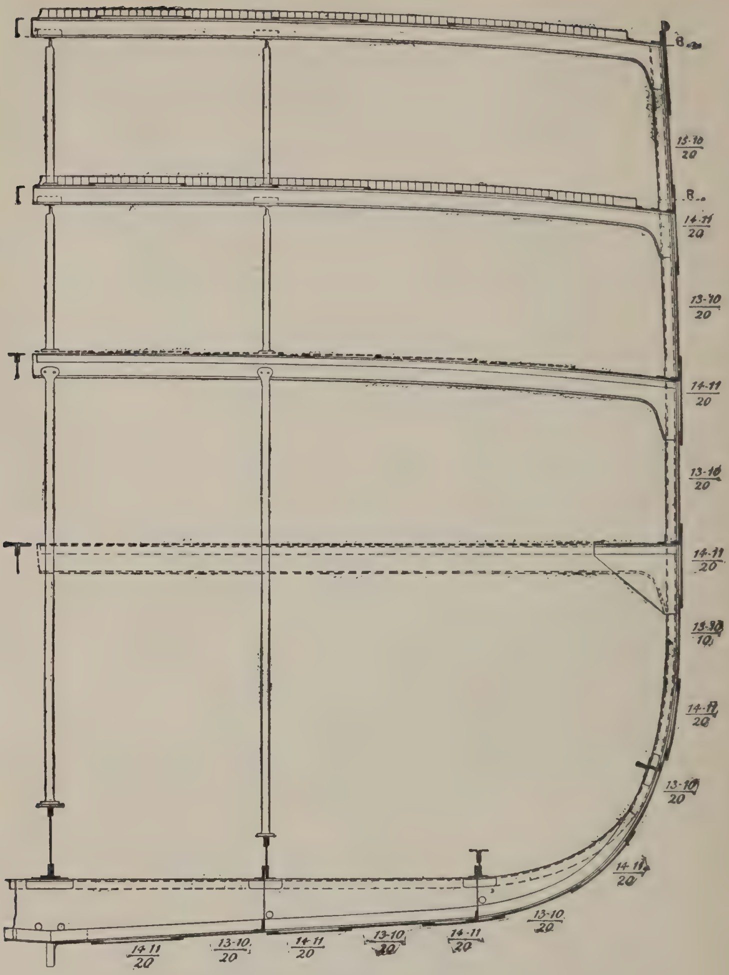
Lloyd's Numerals.

½ Girth,	40·75
½ Breadth,	20·5
Depth,	25·83
	87·08
	7
1st No.,	80·08
Length,	301
2nd No.,	24104

Frames, $5 \times 3\frac{1}{2} \times \frac{8-7}{20}$ spaced 24 inches.
Reverse frames, $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{8}{20}$.
Floors, $24\frac{1}{2} \times \frac{10-8}{20}$.
Centre keelson, $25 \times \frac{14-12}{20}$.
Keelson continuous angles, $6\frac{1}{2} \times 4 \times \frac{9}{20}$.
Intercostal keelson plate, $\frac{9}{20}$.
Complete steel deck, $\frac{7}{20}$ thick on main deck.
Upper deck beams, $7\frac{1}{2} \times 3 \times \frac{10-9}{20}$ bulb angles on every frame.
Middle deck beams, $10 \times \frac{10}{20}$, bulb plate with } on every alternate
Double angles $3\frac{1}{2} \times 3\frac{1}{2} \times \frac{7}{20}$ } frame.
Hold beams, $11 \times \frac{11}{20}$, bulb plate with } on every tenth frame.
Double angles, $5 \times 4 \times \frac{9}{20}$ }
Upper deck stringer plate, $43 \times \frac{10}{20} - 36 \times \frac{8}{20}$.
Middle deck stringer plate, $62 \times \frac{10}{20} - 36 \times \frac{8}{20}$.
Hold stringer plate, $40 \times \frac{9}{20} - 31 \times \frac{8}{20}$.
Gunwale angle bar, $4\frac{1}{2} \times 4\frac{1}{2} \times \frac{10}{20}$.
Sheer strake, $42 \times \frac{15-10}{20}$.
Garboard strake, $36 \times \frac{12-11}{20}$.
Keel, $10 \times 2\frac{5}{8}$.
Hold pillars, $3\frac{5}{8}$.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for $\frac{3}{4}$ L amidships.
To bilge keelson, a bulb plate is added for $\frac{3}{5}$ L amidships, and an intercostal plate for $\frac{1}{2}$ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added all fore and aft.
Centre keelson increased in depth.
To side keelson, a bulb is added for $\frac{1}{2}$ L amidships.
To bilge stringer, an intercostal plate is added for $\frac{3}{5}$ L amidships.



Under 36 feet depth (also under 39 feet).
15·5 depths to middle deck in length.
12·5 depths to upper deck in length.

FIG. 47.—DIMENSIONS OF FRAMEWORK FOR VESSELS LESS THAN 36 FEET IN DEPTH.

Note.—The scantlings are for the vessel under 36 feet depth, all of which are shown in clear black lines. The Fig. is drawn to the under 39 feet depth in order to show the introduction of the new tier of beams indicated by dotted lines. Such a vessel would require both additional topside and bottom strengthening.

Lloyd's Numerals.

½ Girth,	52·5
½ Breadth,	25
Depth,	35·83
	113·33
	7
1st No.,	106·33
Length,	448
2nd No.,	47635

Frames, $6 \times 3\frac{1}{2} \times \frac{10-9}{20}$, spaced 25 inches.
Reverse frames, $4\frac{1}{2} \times 3\frac{1}{2} \times \frac{10}{20}$.
Floors, $32 \times \frac{10-8}{20}$.
Centre keelson, $36 \times \frac{14-13}{20}$.
Keelson continuous angles, $6\frac{1}{2} \times 4\frac{1}{2} \times \frac{10}{20}$.
Intercostal keelson plates, $\frac{9}{20}$.
Foundation plate, $18 \times \frac{10}{20}$.
Complete steel deck to upper deck, $\frac{9}{20}$.
Complete steel deck to middle deck, $\frac{8}{20}$.
Upper deck beams, $9 \times 3 \times \frac{12-11}{20}$, bulb angle on every frame.
Middle deck beams, $9 \times 3 \times \frac{12-11}{20}$, bulb angle on every frame.

$$\left.\begin{array}{l}\text{Lower deck beams, } 12 \times \frac{11}{20}\text{, with} \\ \text{Double angles, } 3\frac{1}{2} \times 3\frac{1}{2} \times \frac{9}{20}\end{array}\right\}\text{ on every 2nd frame.}$$

Upper deck stringer plate, $64 \times \frac{13}{20} - 51 \times \frac{9}{20}$.
Middle deck stringer plate, $64 \times \frac{11}{20} - 51 \times \frac{9}{20}$.
Lower deck stringer plate, $56 \times \frac{10}{20} - 44 \times \frac{8}{20}$.
Gunwale angle bar, $5 \times 5 \times \frac{11}{20}$.
Sheer strake, $46 \times \frac{15-12}{20}$.
Garboard strake, $36 \times \frac{15-14}{20}$.
Keel, $12 \times 3\frac{1}{4}$.
Hold pillars, 4.

Additions for Extreme Length.

Sheer strake doubled for whole width, for $\frac{3}{4}$ L amidships.
To strake below sheer strake, $\frac{2}{20}$ is added for $\frac{1}{2}$ L amidships.
To upper deck stringer plate, $\frac{2}{20}$ is added for $\frac{3}{5}$ L amidships.
To side keelson, continuous plate is added for $\frac{3}{4}$ L amidships.
To bilge keelson, continuous plate is added for $\frac{1}{2}$ L amidships.
To bilge stringer, intercostal plate is added for $\frac{3}{5}$ L amidships.
Centre keelson increased in depth.

Relation of Strength to Dimensions—Notes on "Midship Sections."—In considering the subject of strains, it was found that both longitudinal and transverse strains decreased towards the ends of the vessel, being greatest on each side of midships. Naturally, therefore, in turning to the transverse sections (Figs. 41 to 47), we expect to find a corresponding arrangement of structural strength. Such, indeed, is the case. In the transverse framing the frames and floors maintain their maximum size for three-fifths of the vessel's length amidships, and are reduced in thickness for the remaining one-fifth of the length at each end. The floors are carried up the bilge to a height of twice their midship depth above the top of the keel, for one-fourth of the midship length of the vessel. Fore and aft of this distance, the ends are gradually lowered until the tops of the floors are level. At the extreme ends, however, the floors are increased in depth, as subsequently shown.

The height to which the reverse frames are carried varies according to the transverse dimensions of the vessel. When Lloyd's first number is below 45, the reverse frames are carried across every floor plate, and up the frame to the upper part of the bilges; when 45 and below 57 they extend alternately to the gunwale, and high enough to enable the double angle stringer above the bilges to be securely connected; or, if hold beams are fitted, high enough to get a good connection to the beam stringer angle. When the number is 57 and above, the reverse frames extend alternately to the gunwale and the stringer next below. When the number for sailing vessels reaches or exceeds 75, the reverse frames extend to the gunwale on every frame.

Except in spar- and awning-decked vessels, and in poops and forecastles, the beams, exclusive of hold beams, where less than three-fourths the length of the midship beam, are somewhat reduced—in many cases—in both depth and thickness.

In the vessels of which Figs. 41, 42, and 43 are midship sections, only one tier of beams is required; but immediately the depth reaches and exceeds 15 feet 6 inches (Lloyd's depth), a tier of widely-spaced hold beams is fitted (Figs. 44 and 45), with a continuous stringer plate on the ends. This, together with the gradual growth of the other framing, provides the additional transverse and longitudinal strength demanded by greater depth and length. When 24 feet is reached and exceeded, another tier of beams is required (Fig. 46).

When the depth reaches 32 feet 6 inches, although another tier of beams is not required, a stringer plate supported on alternate frames by large bracket knees has to be fitted, and on its inner edge is rivetted a large angle of the size of the centre keelson angles, converting it still further into an efficient girder.

When 36 feet depth is reached, the additions shown by the dotted lines in Fig. 47 are required. Here we have a fourth tier of beams of extra strength fitted to every tenth frame. These are known as *orlop beams.*

Turning to the longitudinal framework, we find similar reductions in the scantlings taking place. The centre keelson plate standing upon the top of the floors, together with its rider plate, maintains the midship thickness for one-half the vessel's length amidships. Beyond this length considerable reduction takes place in the thickness, and the rider plate disappears altogether before and abaft of the three-fourths length amidships. Stringer plates at the ends of beams retain their midship dimension for one-half the vessel's length. Throughout the remaining one-fourth length at each end they gradually diminish in both breadth and thickness. The number of hold stringers and keelsons to below the bilge is regulated entirely by the depth of the vessel. The sizes of all the large angles for keelsons and stringers in the hold are the same as the centre keelson angles.

A glance at the outside shell plating covering the frames also shows a reduction, and this takes place on the one-fourth length at each end.

Where a steel deck of seven-twentieths of an inch or over is fitted, it is reduced in thickness fore and aft of the half length amidships. A little consideration will soon make it obvious that it would be absurd to deal out to every vessel of similar "2nd numerals" exactly similar longitudinal strengthening, for then a long, shallow vessel would receive actually less longitudinal stiffening than a shorter, deep one, since the introduction of hold stringers and keelsons is regulated almost entirely by the depth.

We have already seen that long, shallow vessels with small depth of girder possess less resistance to bending than shorter ones, not to mention shorter and deeper vessels. It is, therefore, the custom with classifying associations to fix upon a standard vessel of a certain number of depths in the length. Lloyd's Committee adopt a length of eleven depths as the standard worked upon. Vessels exceeding these proportions are, therefore, subject to the introduction of additional longitudinal strengthening over the middle of the length. In Figs. 41 to 47, the number of depths in length is 12·5, excepting Fig. 46, which is 11·6, and the additional strengthening therefore required is shown, as far as possible, on their respective sketches, as well as in the table of additions on each diagram.

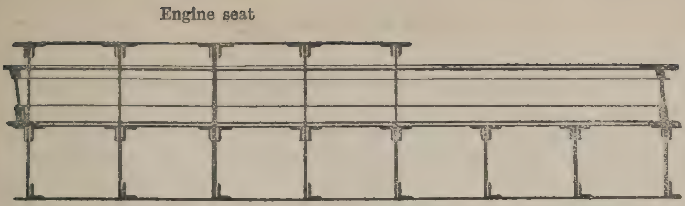
When in three-decked vessels the length is more than eleven times the depth taken from the top of the keel to the top of the *middle deck beams*, special additional strength has to be introduced at the bilge and bottom. Such strength has been introduced into the foregoing midship sections. All vessels having a length of thirteen or more times the depth from the top of the keel to the top of the upper deck beams are to have a substantial erection, such as a bridge, extending over the half length of the vessel amidships.

A perusal of these Figs., with the scantlings written upon them, it is believed will fully verify the foregoing remarks upon the arrangement and growth of structural strength.

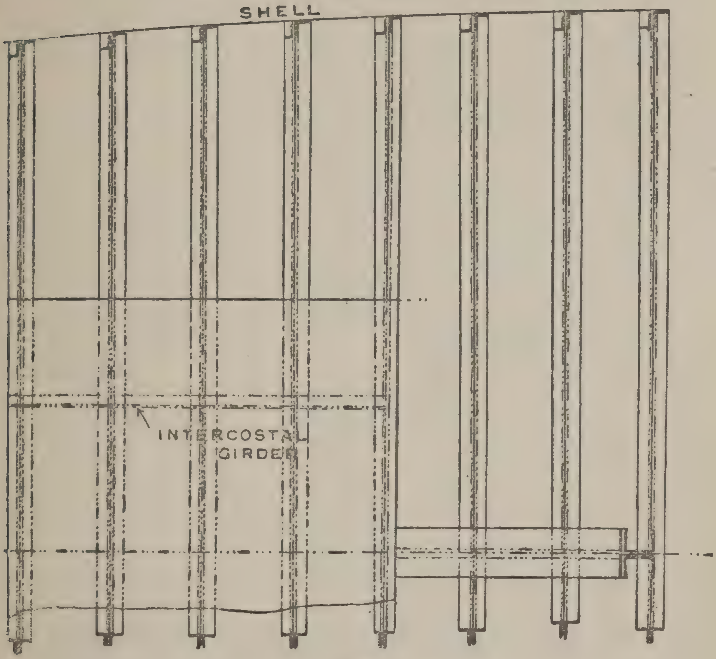
Local Strengthening—Space occupied by Machinery.—*Engine and Boiler Space.*—Perhaps one of the first things which strikes one in studying the arrangement of a steam vessel, from a structural point of view, is the concentration of weight, and also the vibration, especially in vessels of high speed, in the machinery space. In addition to this, there is a break in the arrangement of transverse strength owing to the omission of beams, and even at the upper deck the beams are cut in the way of the engine and boiler casings. The result of all this is to produce the tendency to vertical elongation, and to cause the top sides of the vessel to contract.

Moreover, if the vessel did not possess sufficient rigidity and stiffness to resist working under the vibration of the engines, the evil would rapidly increase, and assume serious dimensions. But, happily, all this can be provided against, and although the methods adopted may vary somewhat for different types of vessels, yet a few general hints may be given.

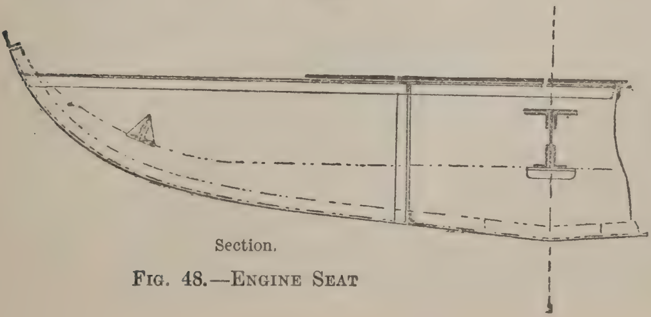
First of all, a good foundation must be secured for both engines and boilers. Lloyd's require that floor plates under engines be one-twentieth of an inch thicker, and under boilers two-twentieths of an inch thicker than are otherwise required, and by this means greater stiffness is given to the bottom of the vessel. No doubt the extra one-twentieth put upon boiler floors is on account of the fact that the damp heat created there has the effect of making corrosion more rapid than elsewhere. At the same time it should be noted that a great deal of the corrosion in this locality is due to neglect, for if the bottoms of vessels were carefully watched, and frequently cement washed, there would be less cause for complaint regarding the condition of the floors of comparatively new vessels, and it would be found that a little care is cheaper in the end than new floors. As a rule, it is found, in vessels with ordinary floors, that the engine foundation or *seat*, as it is more commonly called, has to be built



Elevation.



Plan.



Section.

Fig. 48.—Engine Seat

to a height considerably above the floors. When this is the case, and it is practicable, a splendid seat is constructed by making the floors deep enough to reach to the engine seat, and to extend with horizontal edges from side to side of the vessel. Across the top of all floors in engine and boiler space, Lloyd's require double reverse angles to be fitted at least from bilge to bilge. This not only stiffens the floor, but forms a good means of connection for the thick plating to which the bed plate of the engine is bolted. Intercostal plates, fitted between floors, on either side of the centre line, give further stiffness to the floors, and support for the condenser, &c. (see Fig. 48).

Sometimes, especially in the case of yachts, a watertight trough is fitted in the engine floors immediately under the shafting, which prevents the grease drip from the engine finding its way into the bilges (Fig. 49).

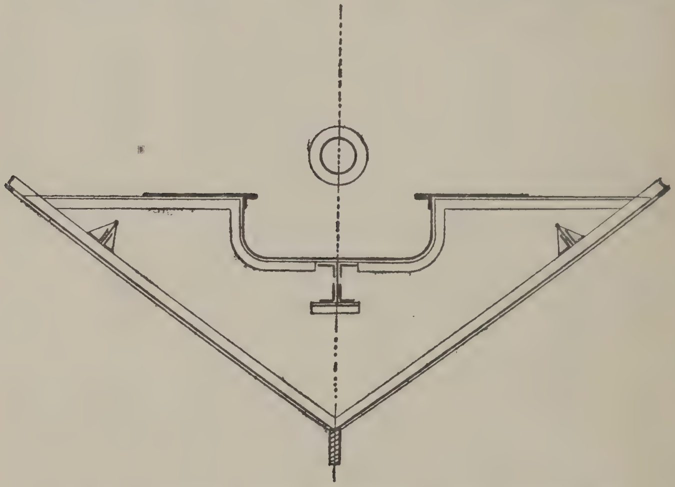


FIG. 49.—TROUGH UNDER ENGINES TO CATCH GREASE DRIP.

Where the floors are not made continuous from keel to engine seat, and from bilge to bilge, a seat has to be built simply in the way of the engine on the top of the ordinary floors; this, however, lacks in efficiency as compared with the previous method.

The boilers, too, require to be fitted on foundations which are firm and rigid, and securely connected with the bottom of the vessel (see Fig. 50). This is done by fixing two or three thick plates called *stools,* to the top of the floor plates under each boiler. The top edges of these plates are cut to shape so as to receive the boiler. They are attached to the double reverse angles on the top of the floors by means of double angles, and round their edges are fitted large double angles. These provide a good surface upon which the boiler can rest. Then, to hold the stools in place and prevent them tripping—that is, inclining one way or another—tie plates are fitted fore and aft, and connected to the double angles. In the case of vessels constructed with double bottoms, for water ballast, as shown in Fig. 51, no erection on the top of the inner bottom is necessary, as it is usually of sufficient height for engines to stand upon. However, the inner bottom plating is increased in thickness in way of the

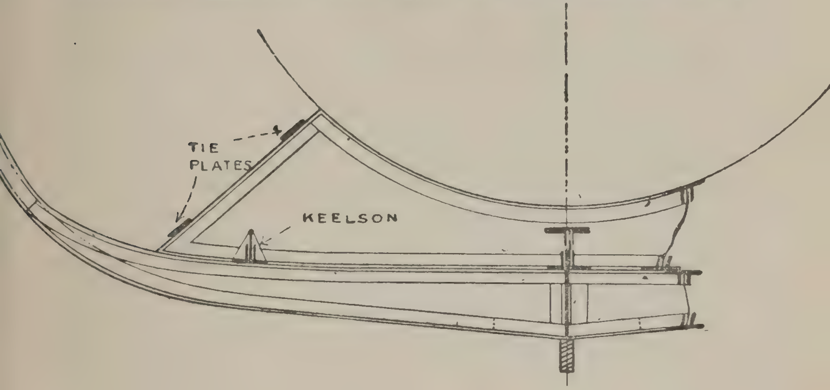


FIG. 50.—BOILER STOOL.

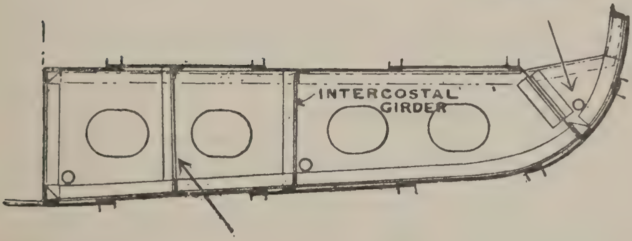


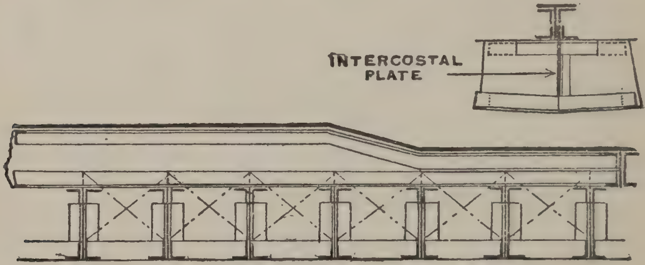
FIG. 51.—SECTION OF DOUBLE BOTTOM FOR WATER BALLAST.

engine and boiler space, and immediately under the engines a thick foundation plate is firmly rivetted. This plate may form a part of the inner bottom plating, or may be rivetted on the top of it. To this the bed plate of the engine is bolted. The boiler stools are rivetted to the inner bottom plating. As in the case of ordinary floors, extra stiffening is required at the bottom of the vessel under the engines and boilers, and this is done by fitting intercostal girders.

Having stiffened the bottom of the ship, it is necessary to provide for the loss of the beams, and also some means of keeping out the sides of the vessel. This is done in exactly the same manner as when hold beams are dispensed with—viz., web frames are fitted. In high speed vessels especially, care should be taken that sufficient of these are introduced. Valuable as web stringers are, in conjunction with web frames, it is found better in the machinery space to fit extra strong beams wherever practicable. Several forms may be adopted according to the size of the vessel (see B C D E and F, Fig. 27).

It will often be found of advantage to further stiffen the frames in the engine and boiler space by fitting all the reverse angles to the upper deck, and in some cases the double reverse bars also.

Sometimes in vessels with the centre keelson fitted on the top of the ordinary floors (Fig. 52), the height of the keelson throws the boiler or boilers too high, and it is necessary to cut the keelson down. Were no compensation made for this reduction in the height of the girder, the weakness at this part would be a most serious defect. Several means, however, may be adopted to recover the strength.



Intercostal plates shown by crossed dotted lines.

Fig. 52.—Intercostal Compensation for Reduction in Depth of Centre Keelson under Boilers.

In the first place it will be seen that, owing to the depth of the keelson being reduced, the sectional area of the keelson is reduced also. This may be recovered by making the central plate thicker at this part until the sectional area has been regained. But even this does not fully recover the loss of strength, for though the sectional area is obtained, yet the reduced depth of the girder proves a loss of strength in resisting longitudinal bending. It, therefore, becomes necessary to increase the sectional area to beyond what it was in its original condition. A good method of compensation is to fit intercostal plates between the floors, and attached to the centre plate by means of its lower angles, as shown in Fig. 52.

Again, it sometimes happens that, in the way of the boilers, it is necessary to reduce the width of the hold stringer plates. Compensation may be made, as in keelsons, by increasing the thickness of the plate in the way of the reduced width, and also by fitting strong angles on the inner edge of the stringer plate.

Mode of Strengthening Ship at Aft End of Shafting.—Leaving the engine and boiler space, and travelling aft, great vibration and strain is thrown upon the vessel, especially when in a seaway from the shafting, by the action of the propeller, it being at one moment totally submerged, and revolving with regular precision, and immediately after the wave has passed, totally or partly out of the water, and racing at a high speed. Provision must, therefore, be made for this. To stiffen the sides of the vessel, the floor plates at the aft end should be made considerably deeper, and towards the stern post they should be carried above the shaft, so that the shaft passes through them. Then again, it is most important that a sound connection be made between the outside plating and the stern post. By the midship sections we see that considerable reduction takes place in the thickness of the end outside plating. To connect thin plating to a massive iron stern post with large rivets widely spaced would likely result in the thin plate being unable to hold the stern post rigid under the strains mentioned, and leakage would ensue. So what is done is to increase the thickness of these endmost plates to at least the thickness of the plating at midships, and thereby get a more evenly balanced connection.

But a further means of rigidly fixing the stern frame is required, and this is done by fitting a deep plate, called a *transome plate*, against the upper part of the stern post, extending across the counter from side to side, and rivetted to the frames. The connection between the stern post and the transome plate is effected by means of strong angles (see Fig. 53, section A B).

It is well known to seamen that considerable leakage often takes place, notwithstanding these precautions to hold the post fixed. An additional means to secure this end is to have another post carried up at the fore side of the stern frame (Y in sketch), and this also is attached to a stout plate carried from side to side of the vessel, and connected with the frames as well as to a bracket plate at the lower deck. By this method, with sound workmanship, and by filling in the space above the propeller aperture between the two parts with cement, leakage is very improbable.

In the case of steamers with twin screws, a different arrangement of supporting the end shafting has to be adopted. One method, after leaving the skin of the ship, is by projecting struts, as shown in Fig. 54.

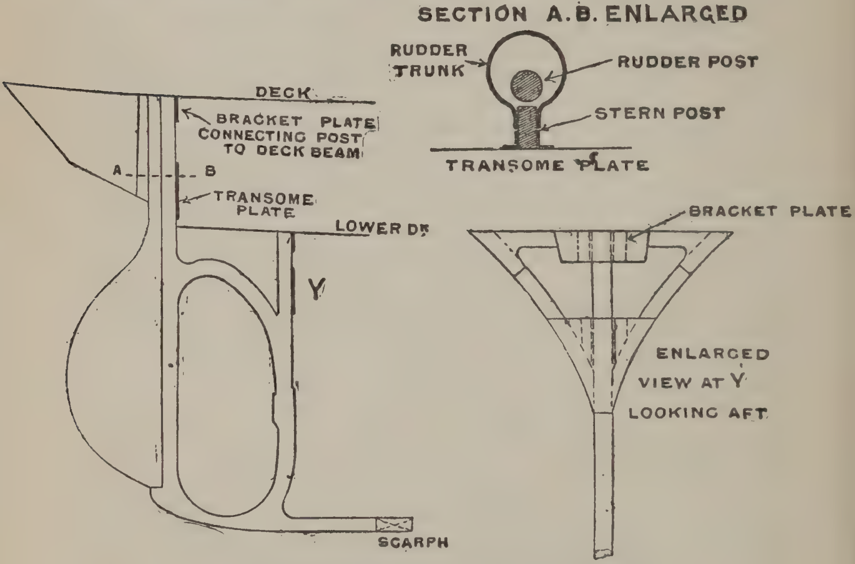
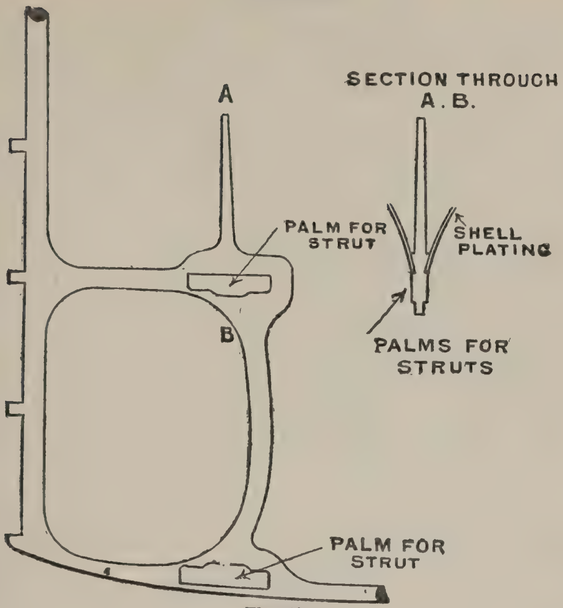


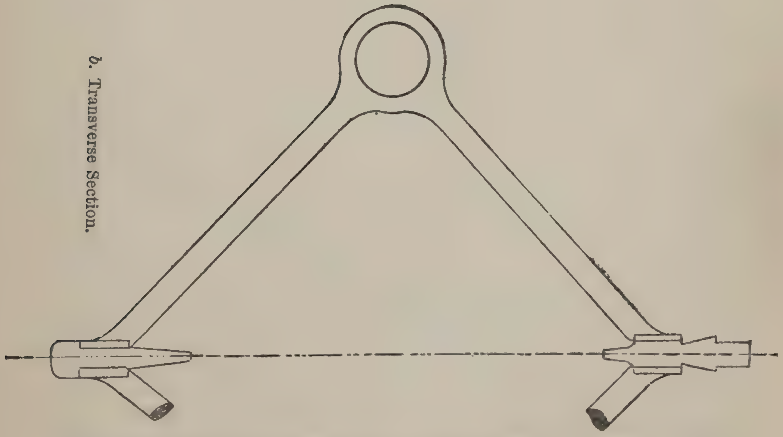
Fig. 53.—Stern Frame and Connection.

The importance of having these struts securely attached to the hull of the vessel will readily be observed, for should any accident happen here, the vessel is entirely crippled. When the screws somewhat overlap each other, and revolve partly in an aperture in the stern frame, a sound and reliable connection of the struts with the stern frame may be made, as shown by Fig. 54, *a* and *b*, the ends of the struts being welded out into broad palms capable of taking a sufficient number of rivets. If there is a weak point



Elevation.

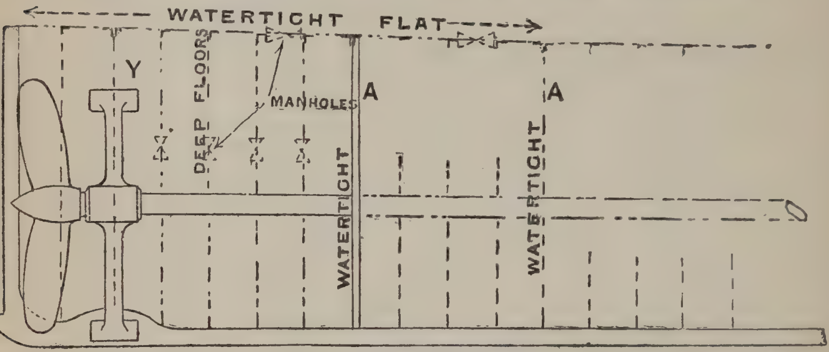
a



b. Transverse Section.

FIG. 54.—CONNECTION OF STRUTS WITH STERN FRAME IN TWIN-SCREW STEAMERS—*a*, ELEVATION; *b*, TRANSVERSE SECTION.

in this method, it is in the fact that both the upper palms of the struts are connected by the same rivets, and also the lower palms, so that on each side of the main post, owing to the vibration of the shafts, there is this tendency to work or sheer the rivets. Each rivet, therefore, bears a double strain. But where no aperture is needed for the propellers, the shell plating is carried out to the after stern post, and another means has to be provided for the connection of the struts. The commonest way, perhaps, is that shown in Fig. 55.



ELEVATION

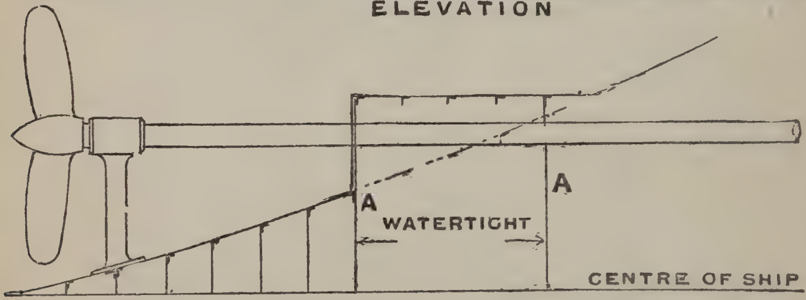


Fig. 55.—Mode of Strengthening Ship at the After End and attaching Struts to Shell Plating.

Here the upper palms are simply fixed on to the outside shell plating. If this were all the connection, it would not take a keen observer to see that the immense vibration of the shafting, especially in high-speed steamers, would simply tear away the plating. It, therefore, becomes absolutely essential that the most competent means be adopted to secure the best and surest connection. Two things have to be aimed at in accomplishing

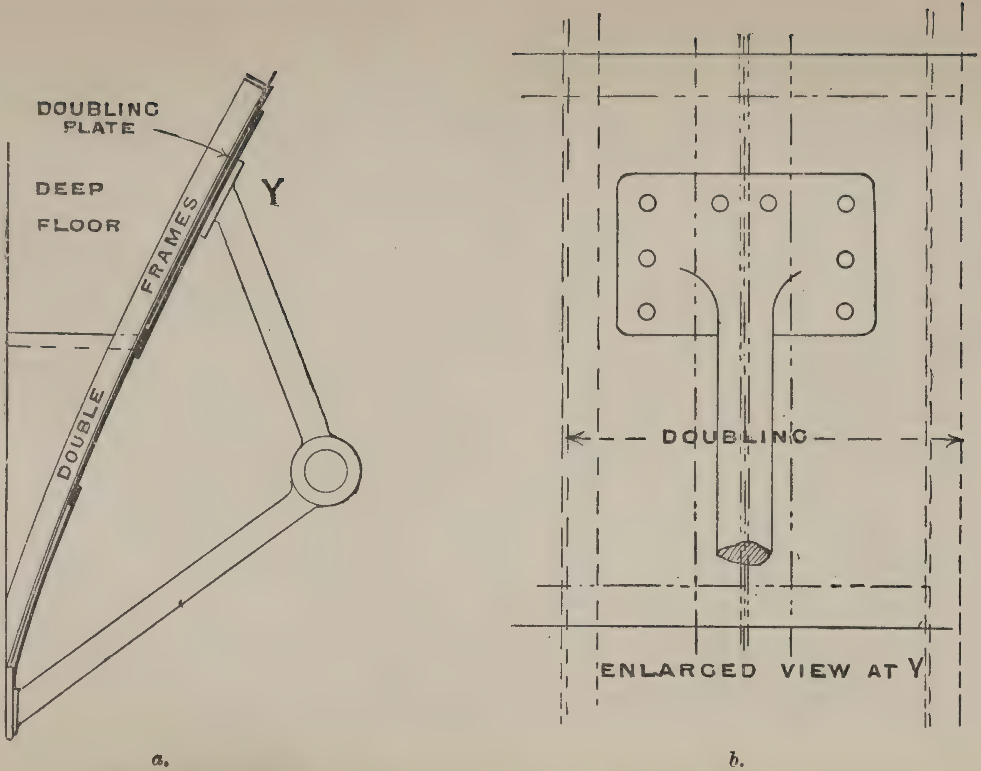


FIG. 55, *a* AND *b*.—MODE OF STRENGTHENING SHIP AT THE AFTER END AND ATTACHING STRUTS TO SHELL PLATING.

this. First, that at the point where the shafts emerge from the hull, the vessel be well stiffened and bound together, so as to reduce the vibration to a minimum, and second, that in the way of the strut connections the ship be well strengthened. A variety of means may be used to attain the former of these. For example, in some vessels the method shown in Fig. 55 might be carried out.

Here a very thick plate or web is placed across the ship from side to side, and securely rivetted to the main frames (A in Fig. 55). Through this plate the shafts pass. If the vessel be not too wide at this part, this alone will form an efficient tie to the two sides, and give the required stiffness. However, in larger vessels, where the screws are further apart, it would be necessary to further stiffen this web by means of angle bars or bulb angles across its face, or even introduce more of these web plates on adjacent frames.

In way of the struts, the following system might be employed:—

1. Carry up all the floor plates from the stern post, to a few frames forward of the struts, above the height of the upper palms (see Fig.).

2. If possible, arrange for a double frame on each side of the vessel to come in the centre of the palms, having thick broad flanges against the outside plating.

3. If the strake of plating, upon which the palms of the struts rest, be an *outside* one, fit a doubling plate between the edges of the two adjacent strakes, and extending fore and aft from the after side of the frame abaft to the fore side of the frame before the double frame angles.

If the strake of plating be an *inside* one, the doubling plate may be fitted on the outside of the shell plating. With this additional strengthening, the palms can now be securely attached to the plating with rivets, through the shell plating, doubling plate, and large double frame angles. Athwartship, the vessel is strengthened by the deep floor plates already mentioned.

In any case, in steam vessels there would be a watertight bulkhead at some little distance forward of the struts. But where in such vessels as these there is the greater possibility of leakage, it would be well to construct a watertight flat at a small height above the upper palms of the struts, so that if leakage did occur, only this compartment would be flooded. From this bulkhead, it would also be well to continue the watertight flat just above the shafting, and extending far enough forward to include the point where the shafts emerge from the shell, since this is another place where leakage might take place (A in Fig.).

This method of strut connection has the advantage of having the strain of the vibration of only one of the shafts thrown upon the rivets connecting the palms with the hull, each upper palm being a separate connection.

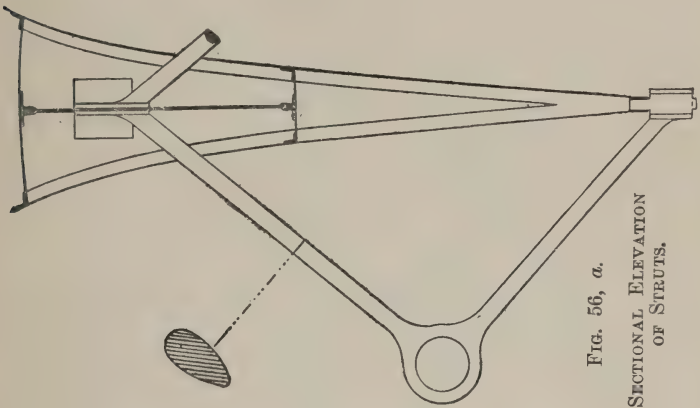
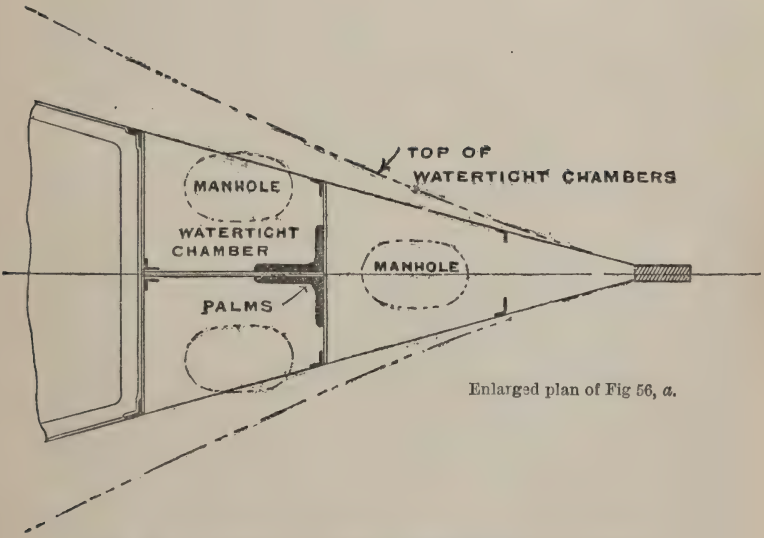


Fig. 56, *a*.

Sectional Elevation of Struts.



Enlarged plan of Fig 56, *a*.

Fig. 56, *b*.—Struts Carried through Shell Plating into Watertight Chamber (Plan).

Another method of strut connection is that shown in Fig. 56, *a* and *b*.

In this case, the struts are carried through the outside plating, and attached to a very thick intercostal plate, fitted between thick transverse plates. To ensure watertightness where the struts pierce the shell, collars would have to be wrought and carefully caulked; and the chambers into which the struts enter should be made watertight also. This method has the same disadvantage mentioned in Fig. 54—viz., the same rivets connect both palms.

A system has been adopted in recent years of supporting the end shafting in large twin-screw vessels, on first leaving the main body of the hull, by carrying out the framing and shell plating round the shafting. Further aft, however, where the shaft is considerably out from the hull, the main frame is carried down in the usual way (Fig. 57), and a piece of frame bar is scarphed on to the main frame, which, together with the shell-plating, is worked round the shaft, binding the projection to and indeed making it an integral part of the structure. By this method the struts are dispensed with, and a strong and efficient means of supporting the shafting is obtained.

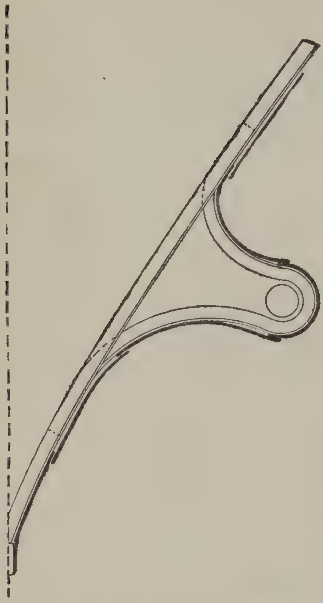
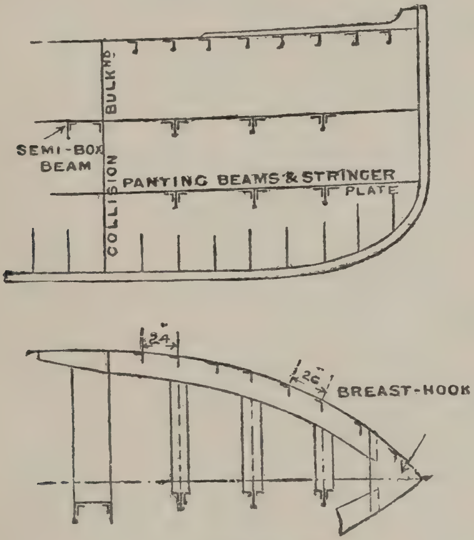


Fig. 57.—Method of Dispensing with Struts in Twin-Screw Steamers.

Panting.—Several means may be adopted to prevent panting, a few of which we shall notice. The common method is to fit plate stringers, called *panting stringers*, in addition to the ordinary stringers of the vessel, extending from abaft the collision bulkhead continuously into the stem, where they are joined by means of a plate called a *breast hook*, uniting, as it were, the two breasts of the vessel. These stringer plates are supported on beams, as shown in Fig. 58.

An objection raised against this method of stiffening is that it forms an isolated rigid girder, and the vessel is inclined to fall hollow on each side of it, especially if subject to encountering ice, as in the Baltic at certain seasons. What is wanted is a more even distribution of strength. This may be obtained by a slight modification in the arrangement of the transverse framing. It will have been noticed that the frames of a vessel are spaced at regular intervals, measured in a fore and aft direction, or on a line passing through the centre of the vessel. Now, at the ends of the vessel, it is found that this spacing is considerably increased. The sketch in the plan of Fig. 58 is an actual and frequent arrangement.



Plan of panting stringer.

FIG. 58.—PANTING STRINGER.

Here it is found that, measuring against the shell plating, the spacing from frame to frame is as great as 26 inches, while on the middle line it is only 24 inches, this latter being Lloyd's requirement. To give stiffness to this part of the vessel, they should be spaced rather more closely, instead of more widely. So that one method is to fit the frames at closer intervals at the fore end, say 2 or 3 inches less than Lloyd's requirements, and measured on the shell instead of on the centre line. It will also be found of advantage to increase the thickness of the shell plating. Whatever method be adopted, it is advisable to considerably increase the depth of the fore end floors.

The introduction of a few extra beams with stringer plates on their ends, where the ordinary stringers are widely spaced, will generally give sufficient stiffness.

Deck Cargoes and Permanent Deck Weights.—To provide against the strain caused by the weight of heavy timber or other deck cargoes, the important point to be observed is that the beams are held rigidly in place at their centres; it is only when the deck sinks at the centre that any damage can be wrought upon the beam knees. Therefore, to provide efficiently against these strains, extra strong stanchions should be fitted under the beams, with well-formed heads, and spaced not more than two

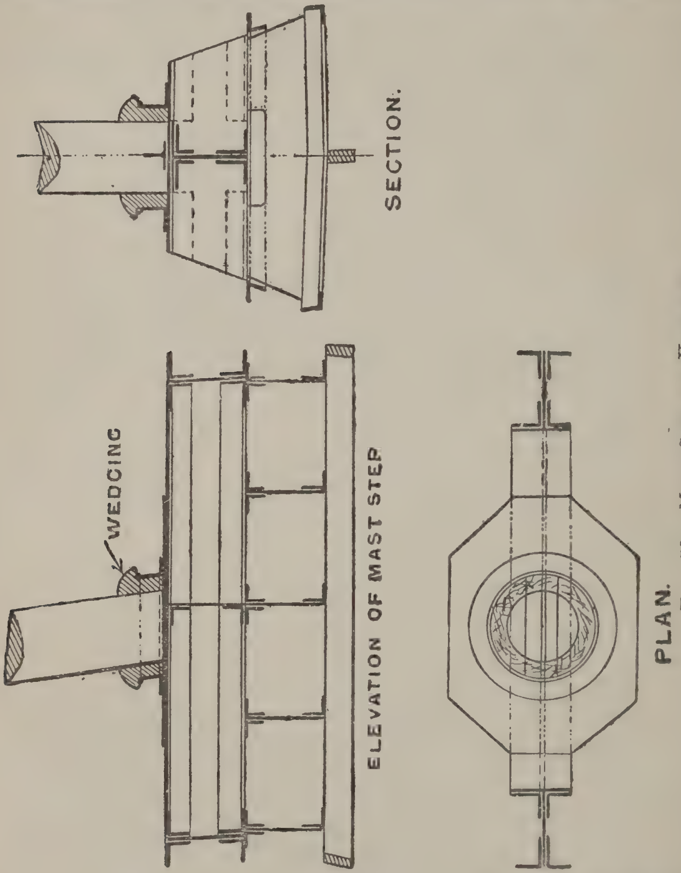


Fig. 59.—Mast Step on Keelson.

frame spaces apart. Where heavy permanent weights are carried on the deck, such as winches, windlass, &c., local strength may be obtained by fitting extra strong beams supported by additional pillars.

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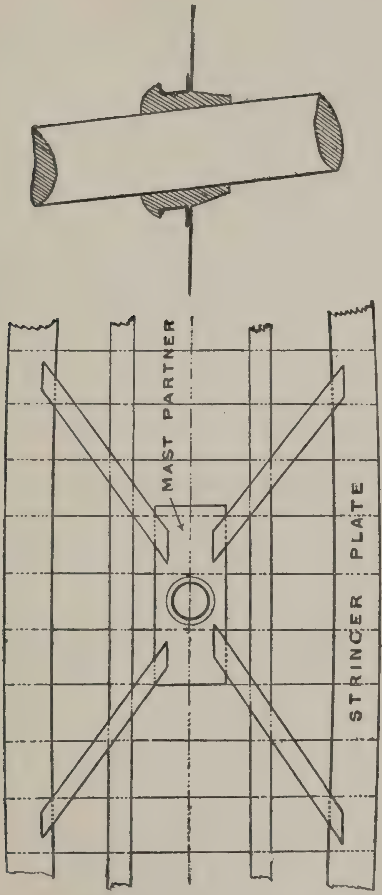


Section of Mast at Deck.

Plan of Deck.

Fig. 60.—Arrangement of Tie Plates distributing Strain from Mast to Beams and Stringer Plates.

Strains from Masts due to Propulsion by Wind.—The important point to be aimed at in this case is to transmit, especially in the case of vessels propelled wholly by wind, the immense strain which is thrown on to the hull, so as to make it as general as possible, though it is classed as a local one. This is accomplished by making good three conditions—

1. That the heel or lowest extremity of the mast be firmly secured and rendered immovable. If the mast is stepped on the top of a centre keelson, the heel may be secured as shown in Fig. 59, a thick plate being firmly attached to the top of the centre keelson, with a circular welded bulb angle well rivetted on its upper face, into which the heel of the mast is stepped and firmly wedged. The mast is prevented from working at its lower extremity by means of a piece of T-bar rivetted to the centre keelson, and notched into the mast heel.

2. That the mast be thoroughly secured at the upper deck. Since a great part of the strain is encountered here, it follows that the means to counteract it should be most efficient. If the deck is plated with iron or steel, and the plate in way of the mast is of reasonable thickness, a stout circular welded angle bulb to receive the wedging round the mast at the deck will provide a satisfactory means of transmitting the strain to the deck as a whole. Should, however, the deck not be entirely plated, a stout plate, called a *mast partner*, should be attached to the beams round the mast, which in its turn should be efficiently attached to the neighbouring beams and stringer plates by tie plates, as shown in Fig. 60. In this way, again, the strain is transmitted to the deck as a whole.

3. That the upper reaches of the mast be held firm, and prevented from working. This is done by having a sufficient number of widely spaced shrouds.

Types of Vessels.—It is scarcely necessary to remind any reader that all vessels are not built for the same purposes, nor to engage in the same trades, or for the same class of harbours. Naturally, therefore, one vessel cannot fulfil all requirements, and be adapted for all traffic, and the result is a considerable variety in the types of vessels built. It is not uncommon to hear the complaint lodged against a vessel that she is ill adapted for her special trade, and the reason undoubtedly is, in many cases, attributable to the fact that the wrong type has been selected to comply with the necessary requirements, neither the shipbuilder nor the naval architect, with their wider experience, having been consulted on the matter. Type, in the majority of cases, depends entirely upon deadweight and internal capacity. The heaviest cargoes, in comparison with their bulk, require the least hold space. With the majority of cargoes it is quite possible to design and fix upon a type of vessel, so that when the holds are filled, she will float at her load water mark. But it must also be obvious that there are some cargoes, such as metal and ores, with which it would be impossible to fill the hold space, and not submerge the disc or extreme load line at the load water mark. However, for all purposes, there is a type of vessel most adapted for a particular kind of cargo. With light cargoes of small density which fill the holds and still leave large freeboard, the shipowner does not mind so long as the freights are satisfactory; but naturally when he gets cargoes of greater density, which bring the vessel down to the waterline obtained by the lighter cargo before her holds are filled, he desires to decrease the freeboard, and to continue to decrease it as the cargoes increase in density. Unfortunately, experience has shown in some cases that this decrease would scarcely cease until the freeboard had approached vanishing point; and thus for the sake of the safety of ships, cargoes, and lives, it has been absolutely necessary to fix upon standard types of vessels adapted to certain freeboards, which, as a rule, are most willingly accepted by shipowners, and indeed, in some cases, more freeboard is given to vessels by the owners themselves than even the Board of Trade Rules demand.

The *heavier* the cargo, especially in ships of great length to depth, the *greater* the bending and twisting strains experienced when among waves, and hence the greater necessity of *increased structural strength.*

Vessels, according to their structural strength, &c., are classified under different names or types, which are often heard and used, but less often understood. There are, again, degrees in each particular type; for example, by 100 A1 at Lloyd's is meant vessels built to the highest class of their particular type, and therefore fulfilling all the requirements for such class; 95, 90, and 80A are lower classes, and do not therefore fulfil the requirements of the one above them. Such vessels have greater freeboard, and therefore carry less deadweight.

First.—The most important of these types is that known as the *Three Deck.* This is the best deadweight carrier, and therefore ranks as the strongest type of vessel built. This is the type of vessel used in illustrating the growth of structural strength for size of vessel in Figs. 41 to 47, and includes the smaller vessels requiring only one or two decks.

Second.—A difficulty sometimes experienced in the three-deck type was, that partly owing to the loss of cargo space occupied by the shafting and enclosed by the tunnel, it was found impossible with some cargoes to trim the vessel by the stern as desired, and hence, for part of the after length, the ship was increased about 4 feet in depth, and became known as the *Raised Quarter Decker* (see Fig. 61). Such vessels are really parts of two different vessels joined together, and each built as near as possible to the previous rule for one-, two-, and three-deck vessels.

The sizes of all floors, frames, and reverses are governed by Lloyd's first number to the main deck. The frames run up to the quarter deck, and the alternate reverse frames also. The number and arrangement of hold beams, beam stringers, and stringers in hold in the way of the raised quarter deck, are in accordance with the increased depth of the vessel at that part, and the height of the reverse frames is regulated by the Lloyd's first number, which the increased depth would give. The aim is to make the raised quarter deck an integral part of the whole, and the result is that a great amount of extra strengthening has to be introduced at the weakest part, which is in way of the break, by overlapping the decks and stringers, doubling the sheerstrake, and fitting webs between the overlapping part of the two decks, so as to better bind the structure together (see A, Fig. 61). As the three-deck and the raised quarter-deck vessels are types which secure least freeboard, it is usual and certainly of great value to erect a bridge over the engines and boilers, and thus protect this most important part from the inroad of the sea. In addition to this, for the accommodation of the crew and passengers, a forecastle or poop is often erected, which, according to their respective values of affording additional effective buoyancy, may further be a means of reducing the freeboard (see Chapter on "Freeboard").

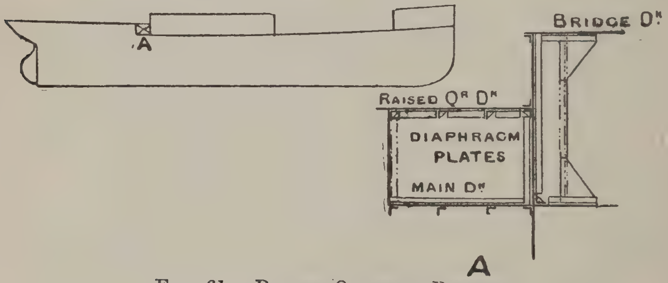


Fig. 61.—Raised Quarter Decker.

Third.—When a vessel is required to carry cargoes of lighter density, it is usual to adopt the *Spar-Deck type*, as these vessels, while possessing the same interior cubical capacity as the three deck, are of lighter construction, and have greater freeboard.

Fourth.—Where the 'tween decks is required for passengers, or to carry very light cargoes of great bulk, the *Awning-Deck type* is usually chosen, as the awning deck is simply a light, entirely-closed, superstructure over the main deck. Being of lighter construction she is less capable than either the three-decker or the spar-decker for carrying deadweight, and therefore has the greatest freeboard.

Perhaps the simplest way of comparing the structure of these types of vessels will be by referring to a midship section of each of them.

Let Figs. 62, 63, and 64 be midship sections of three vessels identical in their exterior appearance, each being 260 feet long, 35 feet beam, and 24 feet depth to the uppermost deck at the side from the top of the keel. Fig. 62 is the midship section of the three-decked type.

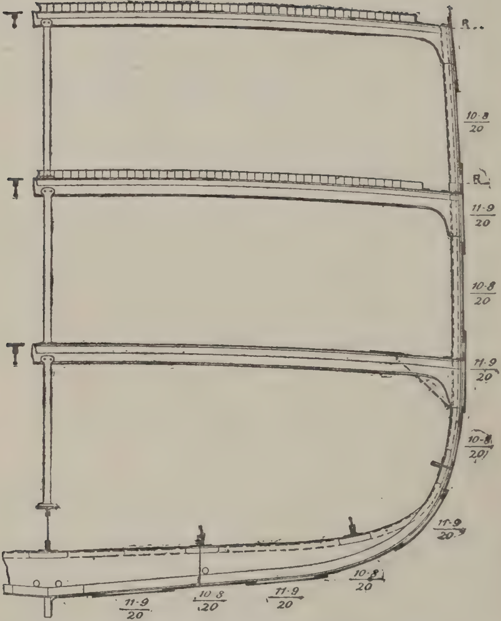
Fig. 63 is the midship section of the spar-deck type, the spar deck being the uppermost deck, and 7 feet above the main deck.

Fig. 64 is the midship section of the awning-deck type, the awning deck also being the uppermost deck, and 7 feet above the main deck.

We have already observed that Lloyd's first number governs the sizes of all the frames, reverse frames, floors, bulkheads, and pillars, and that the depth of one-, two-, and three-decked vessels is taken to the uppermost deck. In the case of spar- and awning-decked vessels, the depth and girth are only taken to the main deck, with the result that the first number for these vessels is considerably reduced, hence the difference in the sizes or *scantlings* of the frames, reverses, floors, bulkheads, and pillars (compare respective sections). Then, with a reduced first number follows a reduced second number, governing the sizes of the outside plating, keelsons, stringers, &c.

Thus far the spar- and awning-decked vessels are identical, so we must note the distinction.

Spar-decked vessels, according to Lloyd's, are supposed to have three tiers of beams, and to be not less than 17 feet depth from the top of the keel to the main deck. Should the depth be less than this, a modification must be made in the freeboard assigned. In all cases the frames extend from the keel to the gunwale; the reverse frames extend to the main and spar decks alternately; a thick sheerstrake is fitted to both the main and spar decks; the side plating above the main-deck sheerstrake is less in thickness than that below; the main and spar decks, when of wood, are each 3½ inches thick, laid and caulked; spar deck beams, stringer and tie plates are lighter than those required for the upper deck of three-decked vessels. Since the depth is only taken to the main deck, and the strength above the main deck is considerable, greatly increasing the efficiency of the ship girder in resisting longitudinal strains, they do not require any additional strengthening for extreme proportions until over 13 depths to length, while in the three-deck type over 11 depths to upper deck in length is considered an extreme proportion, thereby requiring additional strengthening.



Three-deck Type—10·4 depths to upper deck in length.
14·5 ,, middle ,, ,,

FIG. 62.—MIDSHIP SECTION OF A THREE-DECKED TYPE OF VESSEL.

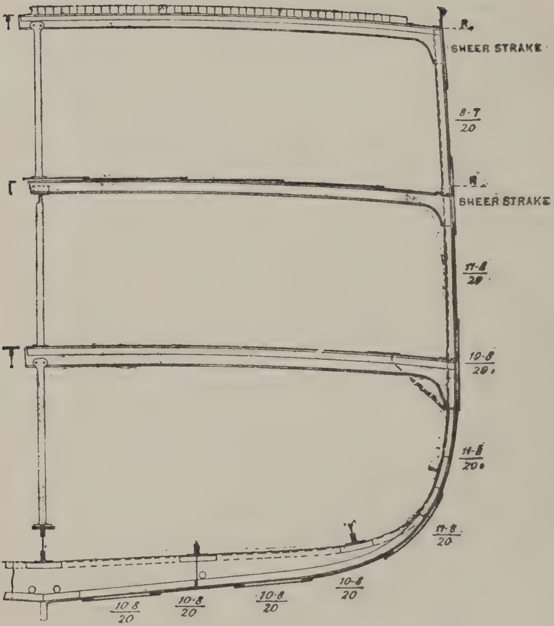
Lloyd's Numerals.

½ Girth,	39·1
½ Breadth,	17·5
Depth,	24·73
	81·33
	7
1st No.,	74·33
Length,	258
2nd No.,	19177

Frames, 5 × 3 × $\frac{8-7}{20}$, spaced 24 inches.
Reverse frames, 3 × 3 × $\frac{7}{20}$.
Floors, 23½ × $\frac{9-7}{20}$.
Centre keelson, 22½ × $\frac{13-11}{20}$.
Keelson continuous angles, 5½ × 4 × $\frac{9}{20}$.
Intercostal keelson plate, $\frac{8}{20}$.
Upper deck beams, 7½ × $\frac{7}{20}$, bulb plate with
Double angles, 3 × 3 × $\frac{6}{20}$ } on every 2nd frame.
Middle deck beams, 8½ × $\frac{8}{20}$, bulb plate with
Double angles, 3 × 3 × $\frac{7}{20}$ } on every 2nd frame.
Hold beams, 9½ × $\frac{9}{20}$
Double angles, 4 × 4 × $\frac{8}{20}$ } on every 10th frame.
Upper deck stringer plate, 52 × $\frac{10}{20}$ – 31 × $\frac{8}{20}$.
Middle deck stringer plate, 52 × $\frac{10}{20}$ – 31 × $\frac{8}{20}$.
Hold stringer plate, 34 × $\frac{9}{20}$ – 26 × $\frac{8}{20}$.
Gunwale angle bar, 4½ × 4½ × $\frac{9}{20}$.
Sheer strake, 42 × $\frac{13-10}{20}$.
Garboard strake, 36 × $\frac{12-11}{20}$.
Keel, 9½ × 2½.
Hold pillars, 3⅜.
Upper deck, 4 inches thick, laid and caulked.
Middle deck, 3½ inches thick, laid and caulked.

Additions for Extreme Length.

Centre keelson increased in depth.
To side keelson, a bulb is added for ½ L amidships.
To bilge keelson, a bulb is added for ⅔ L amidships.
To bilge stringer, an intercostal plate is added for ½ L amidships.



Spar-deck type—14½ - 2 = 12½ depths in length.

FIG. 63.—MIDSHIP SECTION OF A SPAR-DECKED VESSEL.

Lloyd's Numerals.

½ Girth,	32·1
½ Breadth,	17·5
Depth,	17·73
1st No.,	67·33
Length,	258
2nd No.,	17371

Frames, 4 × 3 × $\frac{7-6}{20}$, spaced 23 inches.
Reverse frames, 3 × 3 × $\frac{7}{20}$.
Floors, 20½ × $\frac{8-7}{20}$.
Centre keelson, 17 × $\frac{12-10}{20}$.
Keelson continuous angles, 5 × 4 × $\frac{9}{20}$.
Intercostal keelson plate, $\frac{8}{20}$.
Complete steel deck, $\frac{6}{20}$ on spar or main deck.

$$\left.\begin{array}{l}\text{Spar deck beams, } 7\times\frac{7}{20}\text{, bulb plate with}\\ \text{Double angles, } 3\times 3\times\frac{6}{20}\end{array}\right\}\text{ on every 2nd frame.}$$

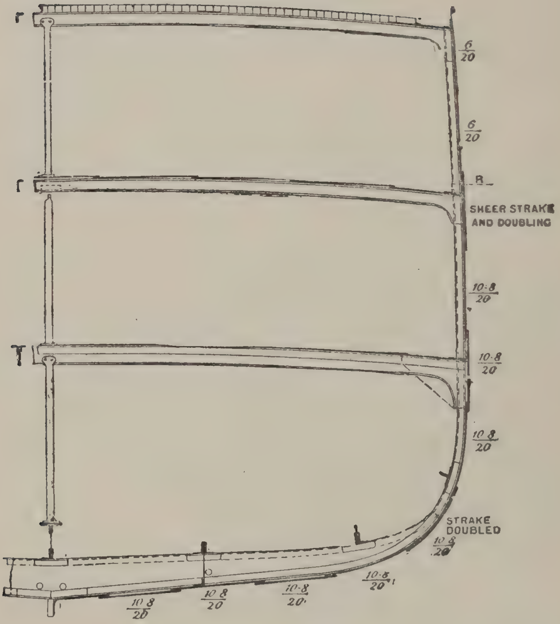
Main deck beams, 6 × 3 × $\frac{8-7}{20}$, bulb angle on every frame.

$$\left.\begin{array}{l}\text{Hold beams, } 9\tfrac{1}{2}\times\frac{9}{20}\text{, bulb plate with}\\ \text{Double angles, } 4\times 4\times\frac{8}{20}\end{array}\right\}\text{ on every 10th frame.}$$

Spar deck stringer plate, 44 × $\frac{9}{20}$ − 29 × $\frac{8}{20}$.
Main deck stringer plate, 37 × $\frac{10}{20}$ − 29 × $\frac{8}{20}$.
Hold stringer plate, 32 × $\frac{9}{20}$ − 25 × $\frac{8}{20}$.
Gunwale angle bar, 4 × 4 × $\frac{9}{20}$.
Garboard strake, 36 × $\frac{11-10}{20}$.
Keel, 9 × 2⅜.
Hold pillars, 3.
Spar deck, 3½ inches thick, laid and caulked.

Additions for Extreme Length.

To thickness of sheer strake, $\frac{2}{20}$ is added for ¾ L amidships.
To strake below sheer strake, $\frac{1}{20}$ is added for ½ L amidships.
To bilge keelson, a bulb plate is added for ⅗ L amidships.
To thickness of 2 strakes at bilge, $\frac{1}{20}$ is added for ½ L amidships.



Awning-deck type—14·5 depths in length.

Fig. 64.—Midship Section of an Awning-decked Vessel.

Lloyd's Numerals.

½ Girth,	32·1
½ Breadth,	17·5
Depth,	17·73
1st No.,	67·33
Length,	258
2nd No.,	17371

Frames, 4 × 3 × $\frac{7-6}{20}$, spaced 23 inches.
Reverse frames, 3 × 3 × $\frac{7}{20}$.
Floors, 20½ × $\frac{8-7}{20}$.
Centre keelson, 17 × $\frac{12-10}{20}$.
Keelson continuous angles, 5 × 4 × $\frac{9}{20}$.
Intercostal keelson plate, $\frac{8}{20}$.
Complete steel deck, $\frac{7}{20}$ on main or awning deck.
Awning deck beams, 6½ × 3 × $\frac{8}{20}$, bulb angle on alternate frames.
Main deck beams, 6 × 3 × $\frac{8-7}{20}$, bulb angle on every frame.
Hold beams, 9½ × $\frac{9}{20}$, with Double angles, 4 × 4 × $\frac{8}{20}$ } on every 10th frame.
Awning deck stringer plate, 32 × $\frac{7}{20}$.
Main deck stringer plate, 37 × $\frac{11}{20}$ − 29 × $\frac{8}{20}$.
Hold stringer plate, 32 × $\frac{9}{20}$ − 25 × $\frac{8}{20}$.
Gunwale angle bar, 4 × 4 × $\frac{9}{20}$.
Garboard strake, 36 × $\frac{11-10}{20}$.
Keel, 9 × 2⅜.
Hold pillars, 3.
Awning deck, 3 inches thick, laid and caulked.

Additions for Extreme Length.

Sheer strake, doubled whole width below stringer plate, for ¾ L amidships.
To upper deck stringer, $\frac{1}{20}$ is added for ½ L amidships.
One strake at bilge, doubled for ½ L amidships.

In *awning-decked* vessels all frames extend to the awning deck; the reverse frames extend to the main deck; the side plating above the main deck is greatly reduced, and no sheerstrake is fitted to the awning deck; awning-deck beams are lighter than those required for spar-decked vessels. Since the awning deck is simply a light superstructure, it is necessary that these vessels have a complete main deck laid and caulked. These vessels are considered of extreme proportions when over 11 depths to length, the depth being taken to the main deck.

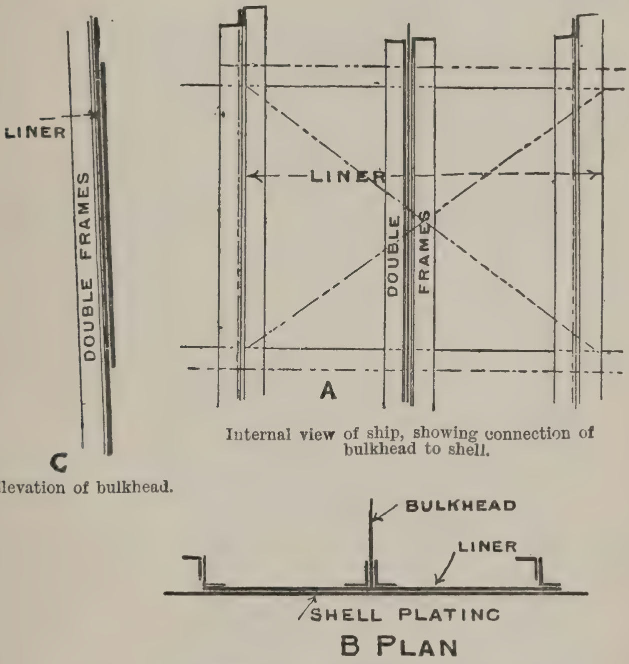
The reader will be greatly aided in grasping these differences by comparing the sections.

Bulkheads.—Watertight bulkheads are iron or steel divisions arranged either transversely or longitudinally, dividing the vessel into watertight compartments. They also give strength, but their chief function is to afford safety, so that should any compartment by any chance or accident be flooded, it is intended that the vessel will still float in comparative safety. Most of the large liners and warships built in these days are divided and subdivided into numerous watertight compartments, having bulkheads far in excess of the requirements of Lloyd's or any other Classification Society. Thus it is possible in many cases for several of these compartments to be damaged and flooded before endangering the safety of the vessel.

Screw steamers classed at Lloyd's have a bulkhead at each end of the engine and boiler space, and another near each end of the vessel. The necessity of having the engines and boilers encased in a watertight compartment is obvious. The foremost or collision bulkhead should be situated at not less than about half the midship beam of the vessel from the stem. The fore end of the vessel being the part most likely to be damaged in case of collision, and the strain which comes from panting tending to make leakage, explains the necessity of having this end of the vessel watertight. At the after end of the vessel, however, though free to some extent from the danger at the fore end, there is severe strain, especially in high-speed vessels, due to the vibration of the shafting. As the danger is, that the aft end shell plate rivets may be worked loose and leakage occur, this part also is made watertight.

Though in short vessels it may be quite possible for one of these five watertight compartments to be flooded, and the vessel to remain afloat, it will be evident that in long vessels the lengths of the fore- and after-holds would be so great that were one of them damaged, and the sea to enter, the loss of buoyancy or floating power would be so great that sinking would be inevitable. Lloyd's, therefore, require that in vessels 280 feet and over in length, an additional bulkhead be fitted in the main hold; and when over 330 feet in length, another bulkhead be placed in the after-hold.

All bulkheads should extend sufficiently high, so that in the event of any compartment being flooded, there would not be the danger of the water pouring over the top of any bulkhead. The collision bulkhead should extend to the height of the uppermost deck, and its watertightness tested by filling the foremost compartment with water to the height of the load waterline.



Internal view of ship, showing connection of bulkhead to shell.

Elevation of bulkhead.

FIG. 65.—CONNECTION OF BULKHEAD TO SHELL.

The bulkhead bounding the engine and boiler space should extend to the upper deck in one-, two-, and three-deck vessels; to the spar deck in spar-decked vessels; to the main deck in awning-decked vessels.

The aftermost bulkhead should extend to the upper deck, or to the spar deck, and should also be tested to ensure watertightness by filling the after peak to the load waterline.

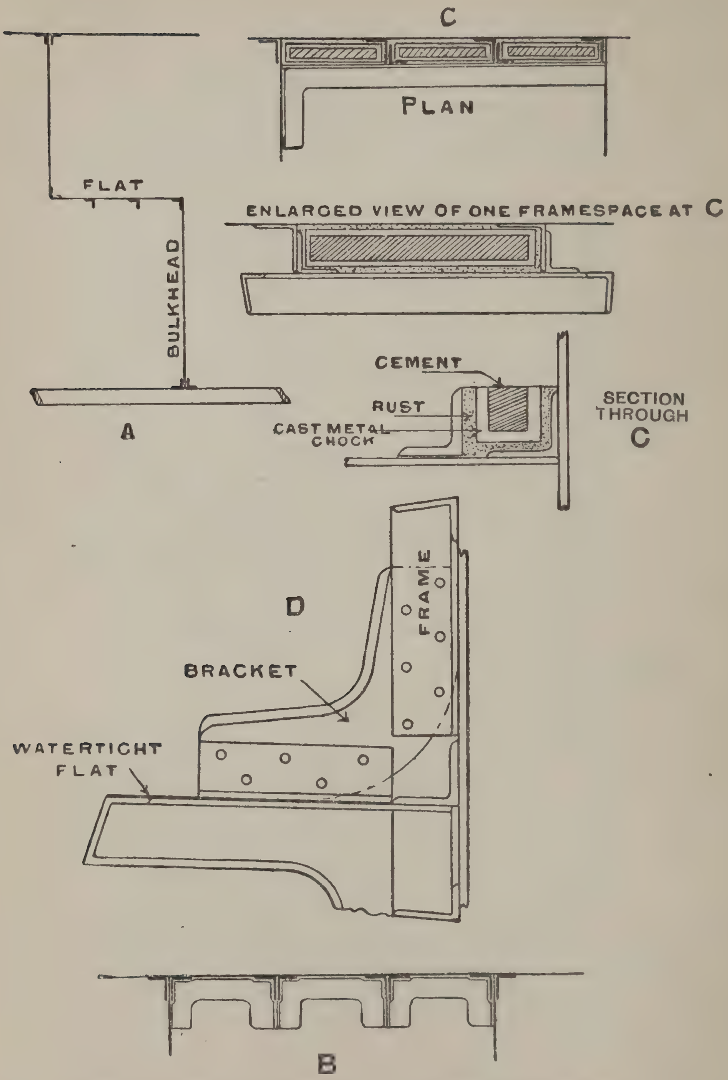


FIG. 66.--RECESSED BULKHEAD AND WATERTIGHT FLAT.

Should the vessel be long enough to require other bulkheads, they should extend to the upper deck in one-, two-, and three-deck vessels; to the spar deck in spar-decked vessels; and to the main deck in awning-decked vessels.

The bulkhead plating is attached to the shell of the vessel by double frames (Fig. 65).

It often occurs that it is not convenient to carry a bulkhead continuously from the keel to its required height, but it is recessed or stepped in the form of a plated flat at an intermediate part, and then continued to its prescribed height. (See A, Fig. 66). However, the watertightness must be maintained. This may be done by cutting the reverse frames and fitting angle collars round the frames in way of the flat, as shown by B, in Fig. 66, or cast iron chocks between the frames (C, in Fig. 66), or else the frames may be cut, and the flat connected to the shell by a continuous angle, with brackets above and below joining the flat to the frames (D, in Fig. 66). When a bulkhead is stepped on a water ballast tank it should be connected by double angles, or in the case where it terminates at a deck, or is fitted in a 'tween decks, it should be attached to the decks by double angles. Where a bulkhead extends above an iron deck, the longitudinal strength is preserved by keeping the deck continuous, and stopping the bulkhead at the under side, then continuing it again above the deck, making the connection by double angles. In fitting iron collars in way of a watertight flat, the reverse frame is cut and the main frame doubled for about three feet to compensate for the break in the reverse frame. Being very expensive, this method is not often adopted. When cast metal chocks are fitted they are first bedded in cement, and a space of about three-quarters of an inch left all round. This space is filled with metal filings—the waste from drilling machines—which, when rusted and caulked, forms very satisfactory watertight work. The edges and butt laps in all bulkheads must be caulked. This is necessary on one side only. It is better to caulk the collision bulkhead on the after side, and the aftermost bulkhead on the fore side. One reason for this is that it is more easily done; but the chief one is, that when these peaks are tested by a head of water, should leakage take place, the exact spot is easily perceived and caulked. For the other bulkheads, it is of little consequence on which side they are caulked.

It is always better to avoid any abruptness in longitudinal strength, and thus all keelsons and stringers should be continuous through bulkheads. This necessitates making the bulkheads watertight at these places by fitting angle collars on one side of the bulkhead, and often plate collars on the other. The angle collar is fitted on the side on which the bulkhead is caulked, and is itself caulked (see Fig. 67).

As has already been pointed out, if any part of the vessel is subject to any weakening, compensation must be made in some form or other to recover the strength. It will be noticed that in attaching bulkheads to the shell plating, a double row of holes has to be punched, and these are spaced 4 to 4½ diameters apart. The result is that the shell plating round the whole girth of the vessel has been greatly weakened. Compensation is made for this by fitting what are called *liners* in the way of all outside strakes where practicable. These are plates extending, as shown in A, Fig. 65, for at least two frame spaces from the toe of one frame to the heel of another, and from the edges of the two inside strakes adjacent. The rivetting in bulkhead liners is arranged where convenient.

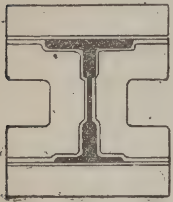
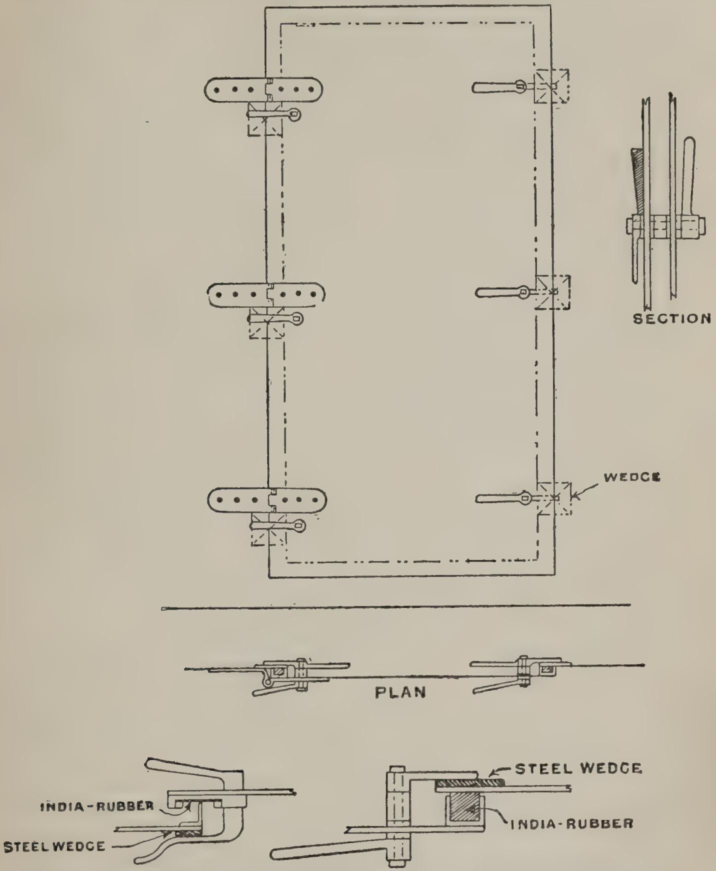


Fig. 67.—Angle Collars Making Bulkhead Watertight round Keelson.

Longitudinal bulkheads continuous all fore and aft in twin-screw vessels also provide a means of subdivision, but at the same time they may afford great longitudinal strength if well constructed and stiffened, especially in very long vessels, and more particularly so in long shallow vessels of the light draught type. Their value in stiffening ships has been proved in cases where, before they were fitted, the vessels suffered greatly from vibration from the machinery, but after they were fitted the vibration was greatly reduced. The reason of this is explained by our girder illustration. The ship, being a hollow girder, has its upper and lower flanges (decks and bottom) the more effectively united, and by this means the whole structure acts more in unison in resisting either local or general strain.

All bulkheads must be thoroughly stiffened if they are to be of any service. To simply fit the sheet of comparatively thin plating of which bulkheads are made, from side to side of the vessel, would be useless in resisting any severe pressure. Bulkhead stiffening is composed of angle bars of the size of the main frames of the vessel placed vertically on one side, 30 inches apart, and on the other side, horizontally, 48 inches apart. According to the dimensions of the bulkhead, additional stiffening may be fitted in the form of semi-box beams (Fig. 58), web plates, and bulb angles. In all cases the collision bulkhead should be additionally stiffened, since this is most liable to danger.

Especially in the case of passenger vessels and yachts, it is often found necessary to have a means of passage through a watertight bulkhead, in order to get from one part of the accommodation to another. This is done by fitting iron doors, which can be closed and secured so as to make the bulkhead perfectly watertight (Fig. 68). When such a door is absolutely necessary, it must be provided, but whenever possible it should be dispensed with, for in case of accident it is very often found that the numerous watertight compartments into which the vessel has



Enlarged sketches showing two different methods of making doors watertight.

FIG. 68.—BULKHEAD WATERTIGHT DOOR.

probably been divided in order to secure safety under the most exceptional circumstances, are rendered worthless, and sometimes a source of danger by these doors being left open, and either forgotten or unapproachable in the hour of need.

Rivetting.—A most important consideration in the production of an efficient vessel is good workmanship, and the greatest attention should be paid to sound rivetting and accurate fitting of butt straps, &c. (Fig. 69). Blind or unfair holes are often the result of carelessness on the part of workmen in marking off the spacing, or in punching the rivet holes. Where such occur, however, the drift punch should be strictly forbidden, as its use not only tears and weakens the plate by the severity of its action, but to get thoroughly watertight work is rendered most difficult, as the rivet cannot fill up the cavities made in so damaging the plate. The drift punch is a tool, as shown in Fig. 70, circular in section, which is driven into the hole, and a space for the rivet torn through.

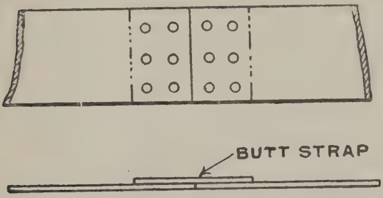


FIG. 69.—BUTT STRAP.

The proper method, when such holes do occur, is to rime them with a tool (Fig. 70), which cuts away any projecting material and leaves a clean hole for the rivet.

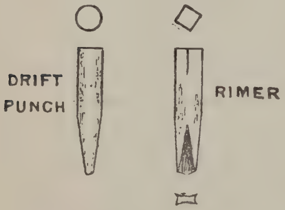


FIG. 70.—DRIFT PUNCH AND RIMER.

After a rivet has cooled down, and is found to be slack, or that the head has been badly laid up, or that on testing leakage takes place, the rivet or rivets should not be caulked to ensure watertightness, as is sometimes done, but taken out and re-rivetted.

Were it not for the additional cost, it would be better to rime out punched holes before rivetting, as this would not only clear the rivet holes, but to some extent restore the strength of the plate, which is weakened by the severity of the action of punching. Though much more costly, by far better work is obtained by drilling rivet holes, as this process not only gives fairer holes, but does not by its action weaken the plate.

In punching rivet holes in plates or angle bars, the holes are always punched from the *faying surfaces*—that is, from the surfaces which are to lie against each other. By this means the plates fit hard up to each other, as a rag edge is made on the outer surface of the plate in punching.

Thus in the plates in A, Fig. 71, the holes are punched in the direction shown by the arrows. In machine punching, the rivet holes gradually increase in diameter in the direction in which the punch passes, as shown.

A few forms of rivetting may here be taken with advantage. For watertight work, where one surface of the plating has to be flush, the pan head rivet is undoubtedly one of the best. Its form is as shown in B, Fig. 71.

It will be observed that the neck of the rivet is expanded under the pan head; this, when heated and hammered, completely fills up the hole in plate *a*. In plate *b*, after the rivet hole has been punched, it is drilled by a machine into a more conical form, as shown. This is called *countersinking*. When the rivet head is thoroughly beaten up, it is cut off in a rounded form, leaving it rather full on the flush surface of the plate. In cooling, the rivet contracts, and this further tends to effectually close up the hole. Another form of rivet is shown in C, Fig. 71. The further this rivet is driven into the hole the tighter it wedges itself, and, if well hammered and laid up, it produces good results. It is still further improved if the work is not prominently visible, by laying up a point as shown in D, Fig. 71, producing greater holding power. This also applies to the pan

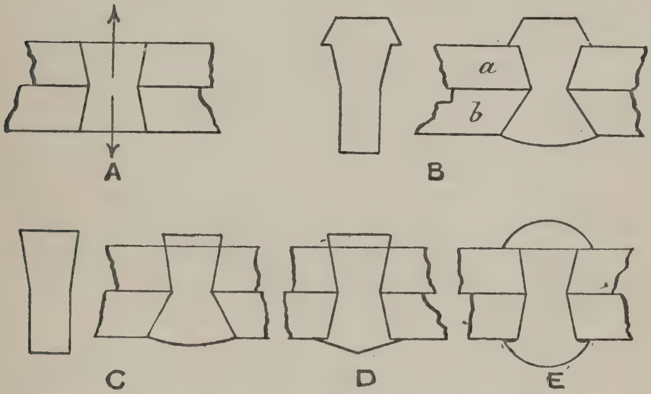


FIG. 71.—MODE OF PUNCHING RIVET HOLES, AND FORMS OF RIVETS.

head rivet, which, as has been proved by experience and experiment, is then the most efficient rivet.

For the sake of their better appearance, the snap head form of rivet has been considerably adopted in many parts of the structure exposed to view, especially in bulkheads. But hand-rivetted snap head rivets have not produced satisfactory results. In clenching up the point of the rivet with the tool called the *snap cup*, the effect is to bring the edges of the rivet close, in the form of a point, as shown in E, Fig. 71, leaving a hollow all round under the head of the rivet.

So long as the rivet is kept dry it works well enough, but when water gets to it the pointed edge rusts, and corrosion is set up in the plate also, with the result that after a time the rivet works loose, and, in many cases, they can be twisted round by the fingers.

Where the work has to be strictly watertight, a far better result is secured by simply hammering the point down hard on the plate, though the appearance is certainly not so taking. Nevertheless, appearance should be sacrificed, rather than efficiency and strength.

Where snap rivetting is performed by a machine, however, the results are very satisfactory, since the machine has the power of more effectually clenching up the point of the rivet. But it is only in some parts of the structure where machine rivetting can be carried out, although in every case it is superior to hand rivetting.

CHAPTER VI. (SECTION I.)

STABILITY.

CONTENTS.—Definition—The Righting Lever—The Metacentre—Righting Moment of Stability — Conditions of Equilibrium — "Stiff" and "Tender"—Metacentric Stability—Moment of Inertia—Agents in Design influencing Metacentric Height—How to obtain Stiffness—Changes in Metacentric Height during the Operation of Loading—Stability of Objects of Cylindrical Form—A Curve of Stability—Metacentre Curves—How the Ship's Officer can determine the Metacentric Height and then the position of the Centre of Gravity in any condition of Loading—Effect of Beam, Freeboard, Height of Centre of Gravity above top of Keel, and Metacentric Height, upon Stability—Wedges of Immersion and Emersion—Effect of Tumble Home upon Stability—Stability in Different Types of Vessels.

Definition.—By the term *stability* is meant the moment of force (usually measured in foot-tons, or in inch-tons), by means of which a vessel, when inclined out of the upright position through some external force, immediately endeavours to right herself. Stability is dependent upon design and loading. Many ocean-going craft have not sufficient stability to stand upright when light, and loll over, and some will not stand at all in this condition without ballast. But ships are not built to sail upon the open sea light, and these same vessels may be so regulated in the operation of loading as to be changed into splendid sea boats.

The Righting Lever.—In Chapter II. we explained the meaning of a foot-ton—viz., that 1 ton of force multiplied by a leverage of 1 foot equals 1 foot-ton. Now, if we say that a vessel of 1,000 tons displacement has a righting moment of stability of 2,000 foot-tons when inclined to an angle of, say, 30°, we mean that the weight, 1,000 tons, is acting at a leverage of 2 feet, since 1,000 × 2 = 2,000 foot-tons; and this is the *righting tendency* possessed by this ship when inclined to an angle of 30°. The two factors in the moment of stability are *weight* and *leverage.* The weight is always the total displacement.

The leverage we shall now endeavour to explain.

Fig. 72 represents two midship sections of the same vessel, one floating upright and the other inclined to an angle of about 14°. When she floated in the upright condition, W L was the waterline, the point B is at the same time the centre of buoyancy, or centre of gravity of the water displaced by the ship, and G is, for that kind of loading, the centre of gravity of the ship and her loading. But when the vessel became inclined, as in the sketch, she floated at the waterline W′ L′. Observe what has happened. The displacement has certainly changed in form, but not in total volume or weight; that remains exactly the same, because the weight of the ship and the cargo remain exactly the same. But the centre of buoyancy has moved towards the right to B′, which is the new centre of displacement (that is to say, the new centre of the water displaced by the heeled ship), the old B being no longer that centre. The centre of gravity of the ship and its loading, G, remains in the same position in the ship as before, whatever be the angle of heel, so long as we do not alter the loading. It must always be the centre of weight, and will never move, as just stated, so long as the weights on board remain stationary. The weight of the ship, like all weights, acts vertically downward through its centre of gravity, G, and the pressures of buoyancy act vertically upward through the centre of buoyancy, B or B′, as the case may be. When the ship was upright the two points were in the same vertical line, but after being inclined, their forces acted through their centres in the direction of the arrows on their vertical lines of action, leaving a horizontal distance between them, because they are now not in the same vertical line. The perpendicular, that is to say, horizontal distance between the two vertical lines of action, gives the lever, G Z; and this very important distance, G Z, is

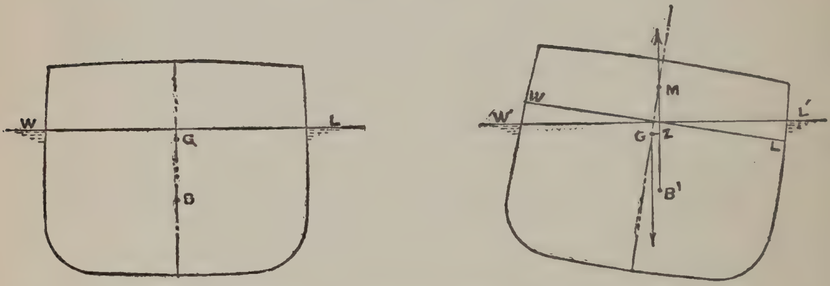


Fig. 72.—Vessel Floating Upright, and Inclined 14°.

the lever we want, and which we mentioned previously as one of the factors in the measure of a vessel's stability.

The Metacentre.—It will be noticed that the vertical line through the centre of buoyancy intersects the centre line of the section of the vessel at the point M. This point is called the *metacentre*, and is always at the intersection of these two lines, which is approximately a fixed point up to angles of about 12° or 15° of heel for ship-shaped objects. Usually, at greater angles the vertical line through the new B^1 no longer intersects the centre line of the ship at the point M.

Righting Moment of Stability.—When M is above G, the lever is properly termed a *righting lever*, for then the action of the buoyancy is to push the vessel again into the upright position, as can easily be seen in Fig. 72. When M is below G, the tendency is to add to the inclining force, and in this case the lever is an *upsetting* one. In the sketch, it is evident that the lever is a righting one, and therefore the displacement of the vessel multiplied by this leverage measured in feet, say, at any particular angle of heel, gives the righting moment of stability in foot-tons for that angle.

Conditions of Equilibrium.—So long as there is a leverage, the vessel, if left free to move, will not remain at rest, or, as it is generally termed, in a state of equilibrium; and the longer the leverage, the greater is the moment tending to bring her back to the upright condition, or to capsize her, as the case may be; and the longer the righting lever up to angles of 12° or 15° in ordinary vessels, the higher must the metacentre be above the centre of gravity. Thus, for a vessel to float upright in a state of equilibrium or rest, it is evident that the centre of buoyancy and the centre of gravity must be in the same vertical line, the force of gravity of the ship, and buoyancy of the water neutralising each other. But it does not follow that in this condition the equilibrium will be stable. For if under the effect of some external force (such as wind) the vessel heel, and the metacentre before heeling be below the centre of gravity, the result will be to push the vessel further over, not necessarily by any means to capsize her, but (it may be) to a position such as to cause the upward vertical line of action of the buoyancy to coincide with the downward line of action of the weight, when the vessel will again remain at rest. When the vessel floated upright before the inclination took place, she might have been compared to a child's play top carefully balanced upon the point, a condition it would not be likely to remain in for a long period. This equilibrium is called *unstable equilibrium*. When the metacentre is above the centre of gravity, and thus, under the least inclination, the vessel immediately endeavours to regain the upright condition, the equilibrium is termed *stable equilibrium.*

"Stiff" and "Tender."—When the metacentre is high (equivalent to large righting leverage), and the righting moment, when the vessel is inclined, is therefore great, the vessel is said to be "*stiff*," and when the metacentre is closer to the centre of gravity, and the vessel naturally possesses small righting leverage for small angles of inclination, she is said to be "*crank*," or, as sailors more commonly say, "*tender*."

When the centre of gravity and the metacentre coincide—that is, when both points occupy the same position—the equilibrium is then *neutral*, neither stable nor unstable.

Metacentric Stability.—Having found the distance between the metacentre and the centre of gravity, the actual lever of stability may be found for small angles of heel not exceeding 15°, by multiplying this distance by the sine of the angle of heel (using natural sines*). Then leverage in feet multiplied by displacement in tons equals righting moment in foot-tons. This stability, which is deduced from the *metacentric height*, or, distance from M to G in Fig. 72, is termed *metacentric stability*.

Our next endeavour must be to discover the position of these points, and to ascertain how they are influenced. The centre of buoyancy we have already studied in Chapter III., and have found its position to be always in the centre of displacement, and also, when the vessel is floating upright, that it is always a fixed point at any particular waterline.

The metacentre also is a fixed point for each successive draught when the vessel floats upright, and thus, by calculating a few of these points, a curve may be constructed, thereby enabling the position of the metacentre to be ascertained at any draught.

But, first of all, let us see how the design or dimensions of a vessel affect the position of the metacentre. The formula for finding the metacentre is :—

$$\frac{\text{Moment of inertia of waterline}}{\text{Displacement in cubic feet}} = \left\{ \begin{array}{l} \text{Height of metacentre above} \\ \quad \text{centre of buoyancy.} \end{array} \right.$$

To give the usual definition of *Moment of Inertia* would probably be to sound the keynote of despair to many a seaman. A simple, though perhaps not very scientific method may be used, reducing this to terms sufficiently plain to be understood by seamen with the most limited mathematical knowledge.

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* See table of natural sines at end of book. Such a table is printed in many books on *Navigation.*

Moment of inertia may be understood as the measure of the tendency possessed by the superficial area of the waterline of any floating object, to remain inert, dead still, or motionless. It must be clearly understood that this moment of inertia applies *only* to the waterline *area* at which the vessel is floating, whether the vessel be a ship, a box, or a log of wood. Thus, the fact that there may be one part of the floating object out of the water, and another part in it, is left entirely out of consideration. Simply *area at the waterline* is dealt with. The formula for moment of inertia of a rectangular-shaped waterline is as follows:—

Cube the side at right angles to the longitudinal axis, multiply this by the length of the waterline, and divide the result by 12.

Note.—Have all the measures in feet to match the displacement.

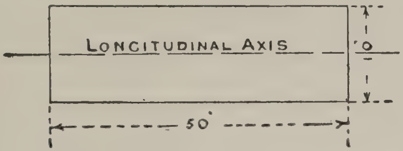

FIG. 73.—PLAN OF WATERLINE.

For example, take Fig. 73, which is a plan of the waterline of a box-shaped vessel 50 feet long, 10 feet broad, and 8 feet draught. The moment of inertia would be:—

$$\frac{10^3 \times 50}{12} = \frac{10 \times 10 \times 10 \times 50}{12} = 4166{\cdot}66 \text{ moment of inertia.}$$

The student should note that since the dimensions and area of all the waterlines of a box-shaped vessel, floating with the bottom parallel to the waterline, are equal to one another, the moment of inertia of each waterline is the same.

But let us proceed to find the height of the metacentre. This is done by dividing 4166·66 by the displacement in cubic feet; the result is the height of the metacentre above the centre of buoyancy. The draught is 8 feet. It is, therefore, evident that the object, being of box form, the centre of buoyancy must be at half the draught, which is 4 feet above the bottom. The displacement in cubic feet will be the volume of the part of the vessel immersed which equals:—

$$50 \text{ feet length} \times 10 \text{ feet breadth} \times 8 \text{ feet draught} = 4000 \text{ cubic feet displacement.}$$

$$\text{Then } \frac{4166{\cdot}66}{4000} = 1{\cdot}04 \text{ feet height of metacentre above centre of buoyancy.}$$

Now the question may be well asked at this stage—Of what value is this result? The only answer is, that these points by themselves are of no practical use, and give no idea whatever of a vessel's stability, until we get the position of the centre of gravity. Let us suppose the height of the centre of gravity from the bottom of the box to be 3 feet (the box having, of course, a load in its lower part, so as to keep the centre of gravity of the loaded box down to 3 feet).

Since the metacentre is 1·04 + 4 = 5·04 feet from the bottom of the box, therefore the distance of the centre of gravity below the metacentre is 5·04 − 3 = 2·04 feet, proving that the vessel is floating in a condition of stable equilibrium. While floating at this draught, imagine a weight of 20 tons already on board to be raised 13 feet. Observe distinctly the new state of affairs, supposing that after the alteration the vessel floats upright. The displacement, the positions of the centre of buoyancy and metacentre are all just the same as previously, no alteration having occurred in the draught. There has, however, been a change in the position of the centre of gravity, thereby affecting the distance between the changed centre of gravity and the unchanged metacentre. Any vertical movement of weight in the box must either raise or lower the centre of gravity, consequently in the case before us, since the weight of 20 tons was raised, it follows that the centre of gravity must have travelled in the direction of the shifted weight. But how far? We have already discovered how to find this in the Chapter on *Moments*, viz. :—

Multiply the weight by the distance it has been moved, and divide by the total displacement (4,000 *cubic feet* = 114·2 *tons*).

$$\frac{20 \times 13}{114 \cdot 2} = 2 \cdot 2 \text{ feet} = \left\{ \begin{array}{c} \text{Distance centre of gravity} \\ \text{has moved upwards.} \end{array} \right.$$

We now see that the centre of gravity instead of being below the metacentre as previously, has risen to (2·2 − 2·04) = 0·16 foot above it. If the box remain upright, it is in a condition of unstable equilibrium, and any exterior force upon it will readily cause it to heel. As the vessel has not sufficient stability to float upright, the vital question is, will she capsize? In the example before us, the vessel having a good freeboard of about 5 feet, the answer is "no," for after inclining to an angle of about 18°, she would remain at rest with this permanent list. Let us again investigate the circumstances. The centre of gravity has remained stationary under the inclination. We observe a slight movement of the centre of buoyancy from its old position to the new centre of displacement. In the earlier stage of this inclining movement, the vertical line through the centre of buoyancy intersected the centre line of the vessel below the centre of gravity, in fact, as always for very small heels, at the metacentre, making a leverage between the vertical lines through the centre of buoyancy and the centre of gravity. This point of intersection being below the centre of gravity, the heeling continues, for the moment is an upsetting one, the buoyancy expending itself in pushing the vessel further over. Reference to Fig. 72 will assist in tracing the movements of these points. However, after inclining to an angle of about 18°, it would be found that the centre of buoyancy had travelled so far out towards the inclining side as to bring it vertically beneath the centre of gravity, the vertical lines of action through these two points coinciding. The upsetting lever having vanished, the box floats in a condition of equilibrium, having neither righting nor capsizing moment, and will move neither towards the port nor the starboard except by the application of sheer exterior force. For vessels of cylindrical form, and, therefore, circular in section, the metacentre is the point of intersection of the vertical line through the centre of buoyancy with the centre line of the cylinder *for all angles* of inclination, and, knowing this, we shall soon see how the whole range of such an object's stability may be readily determined. As we have observed, vessels of ship form differ from cylinders for large angles of inclination, and another method has to be adopted in order to trace out the whole range of stability.

Agents in Design Influencing Metacentric Height.—The two important factors in the design of a ship influencing the height of the metacentre are *beam* and *displacement.* The formula for the moment of inertia of the waterline of a box vessel we have already stated as :—

$$\frac{\text{Length} \times \text{Breadth}^3}{12},$$

so that, as the breadth is cubed, any addition to this dimension must have greater effect in increasing the moment of inertia of any waterline than a similar addition to the length.

The formula for height of metacentre above centre of buoyancy is :—

$$\frac{\text{Moment of inertia of load waterline}}{\text{Displacement}}.$$

It must, therefore, be evident that the smaller the displacement, the greater will be this height. Had the displacement of the box vessel, referred to previously, been reduced by cutting off the bottom corners and making it more triangular in shape, preserving the same area of waterline, a much higher metacentre would have been obtained. Thus, fine vessels with good beam produce the highest metacentres. These points may be more vividly illustrated by means of a few simple examples:—

Let 2 feet be added to the beam of the box vessel with which we have just been dealing, the draught remaining the same. The dimensions will now be—Length, 50 feet; breadth, 12 feet; draught, 8 feet.

$$\text{The moment of inertia} = \frac{50 \times 12^3}{12} = 7200.$$

$$\text{The displacement} = 50 \times 12 \times 8 = 4800 \text{ cubic feet.}$$

$$\frac{7200}{4800} = 1{\cdot}5 \text{ feet} = \text{metacentre above centre of buoyancy.}$$

In the original condition, the metacentre was 1·04 feet above the centre of buoyancy, and 2·04 feet above the centre of gravity.

The metacentre, being raised (1·5 − 1·04 =) 0·46 foot, by the addition of 2 feet to the beam, in its turn increases the metacentric height to (2·04 + 0·46 =) 2·5 feet, greatly adding to the stiffness of the vessel. Had we added 2 feet to the length of the vessel, certainly the moment of inertia would have been increased, but so would the displacement, entirely neutralising what might have been imagined a means of raising the metacentre.

$$\frac{52 \times 10^3}{12} = 4333{\cdot}33 \text{ moment of inertia.}$$

$$52 \times 10 \times 8 = 4160 \text{ cubic feet displacement.}$$

$$\frac{4333{\cdot}33}{4160} = 1{\cdot}04 \text{ feet metacentre above centre of buoyancy, and}$$

the same as the original height.

If 2 feet had been added to the draught, the moment of inertia would have remained the same: $\frac{50 \times 10^3}{12} = 4166{\cdot}66$, and the displacement would naturally have been enlarged, $50 \times 10 \times 10 = 5000$ cubic feet. The evident result must be that in relation to the centre of buoyancy, the metacentre is now lowered, for $\frac{4166{\cdot}66}{5000} = 0{\cdot}83$ foot metacentre above centre of buoyancy, which is less than the original 1·04.

By these simple illustrations it is clear *that beam is the most important factor* in the dimensions of a vessel by means of which a high metacentre is obtained, simply because the breadth of the vessel is used in the third power, while the other dimensions are used only in the first power, in the process of calculation. It will also be noticed that the position of the weights carried governs the position of the centre of gravity of the loaded vessel.

How to Obtain Stiffness.—We have now discovered two means of obtaining stiffness—first, by placing heavy weights as low as possible, thus drawing the centre of gravity down from the metacentre; and second, by adding to the beam to raise the metacentre.

Changes in Metacentric Height when Loading.—We can also the better understand how it is that some vessels, especially when loaded with homogeneous cargoes, get tender when the last part of the cargo is being put on board, and the load waterline approached. For some distance below the load waterline, little or no increase has occurred in the area of the waterline. In fact, where the vessel possesses great *tumble home*,* it may even happen that the width of the waterline at the load line is less than at 1 or 2 feet below it, and we have seen what effect any reduction in the beam has upon the moment of inertia. Now, while with increasing load, no increase may have been occurring in the moment of inertia while nearing the load waterline, the displacement has certainly continued to increase with the increasing load. The metacentre and the centre of buoyancy have, therefore, come nearer each other. But at the same time, the centre of buoyancy has certainly risen above the keel some distance, being now the centre of a greater displacement, and may have risen more than the metacentre has sunk. The result is that the metacentre may actually be higher from the keel than before. But the continuance of the loading producing this rise in the centre of buoyancy above the keel has also raised the centre of gravity above the keel, with the effect of reducing the distance between the metacentre and the centre of gravity—that is to say, the metacentric height is reduced, or, the vessel has become more tender. Before any cargo was placed on board, the metacentre and the centre of gravity had perhaps only 5 or 6 inches between them. In this position, the vessel would be tender, not at all uncommon when light. Now, let the centre of gravity of the unloaded ship be at half the depth of the hold. It is clear that when the operation of loading commences, and as long as weight is being placed below the centre of gravity, the centre of gravity must be gradually lowering, and the vessel becomes very stiff in consequence, but as cargo continues to be loaded, and the holds are about filled, the centre of gravity rises again. It is also evident, that if more heavy cargo be placed above the original centre of gravity than below it, the centre of gravity must be higher than it was previously. We must not forget, however, that the metacentre has varied with every change of draught. If we had a curve of metacentres for the vessel, we could readily ascertain its correct position. If it were found that we had so loaded our vessel as to bring the centre of gravity again into proximity to the metacentre, the result would naturally be a small metacentric height and a tender ship.

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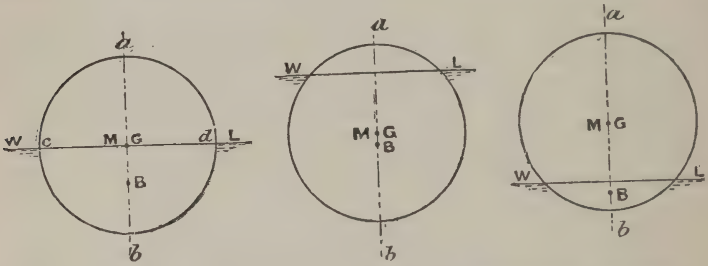
* "Tumble home" is the difference between the amidship breadth at the uppermost deck edge and the moulded breadth.

Stability of Cylindrical Objects.—At this stage, it will repay us to give a little attention to the stability of objects of cylindrical or cigar form, and from these simple shapes to deduce such principles as will help us in dealing with the more complicated ship forms.

Let Fig. 74 be such an object 50 feet long, 10 feet diameter, and for the sake of example, a solid piece of timber, floating half



Figs. 74, 75, 76.—Stability of Floating Cylindrical Objects.

immersed—that is, at 5 feet draught. The centre of gravity will be in the centre of the log at G. Every reader knows from observation that such an object will float as readily in one position as another, and with any of the points, *a*, *b*, *c*, *d*, uppermost. Such a condition is, therefore, one of neutral equilibrium, and this being the case the metacentre and the centre of gravity must coincide. Let us endeavour to prove this. It is clear that G is the centre of weight. The centre of buoyancy will be in the centre of the half circle in the water at B. If a piece of cardboard were cut to this shape, and balanced upon a point, it would be found to be ·4244 of the half diameter of the cylinder down from the line C D = ·4244 of 5 feet = 2·122 feet. The moment of inertia of the waterline will be

$$\frac{50 \times 10^3}{12} = 4166{\cdot}66.$$

The displacement is

$$\frac{10^2 \times \cdot 7854 \times 50}{2} = 1963 \cdot 5.$$

Therefore, $\frac{4166 \cdot 66}{1963 \cdot 5} = 2 \cdot 122$ metacentre above centre of buoyancy, bringing it exactly up to G, thus proving the fact that the vessel floats in a condition of neutral equilibrium.

Had the above cylinder been made of heavier wood, so as to float deeper, as shown in Fig. 75, its equilibrium would still have been neutral, and in like manner the metacentre and centre of gravity would have coincided.

Or again, had the object been made of lighter material, and floated as in Fig. 76, the equilibrium would have been unchanged, for still the metacentre and centre of gravity would have occupied the one position.

The fact to be remembered from these examples is, that *the transverse metacentre is always the centre of the circular section whatever be the draught.*

But suppose the vessel is hollow, and a weight is placed inside and firmly fixed, with the effect of lowering the centre of gravity, say, 1 foot below the metacentre. The vessel floats, say, at half the diameter draught, 5 feet. To whatever angle the vessel be now heeled, the centre of buoyancy must always be in the centre of the immersed semicircle, and the centre of gravity is immovable in its position.

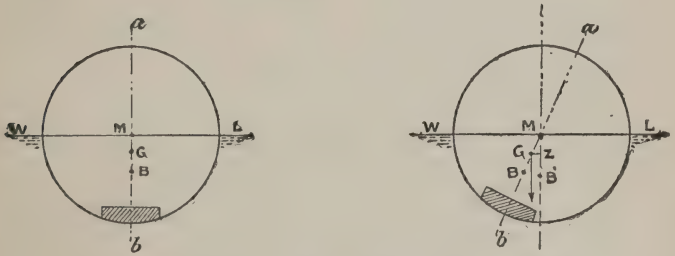


FIG. 77.—VESSEL LOADED WITH A FIXED WEIGHT.

When floating upright, as shown in Fig. 77, the metacentre, centre of gravity, and centre of buoyancy are in the same vertical line; but if the vessel be heeled, the centre of gravity and centre of buoyancy will no longer be in the same vertical line. The distance between the two vertical lines through the points G and B′ indicates the lever of stability, G Z.

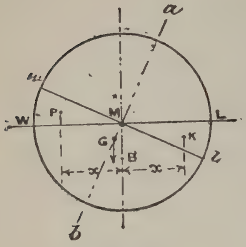


FIG. 78.

In heeling, it is clear that a part of the vessel of wedge shape, L M *l* (Fig. 78), formerly out of the water, is now immersed, and another wedge-shaped part, W M *w*, formerly in the water, has become emerged. Whenever it happens, whatever be the type of floating object, that the immersed wedge is identical in shape with the emerged wedge, with each of their centres the same distance from the vertical line through the centre of buoyancy, this vertical line will intersect at the point M, in the line *a b*, thus keeping the distance from M to G (the metacentric height) the same.

The lever of stability can be found by *multiplying the distance*, M G, *by the sine of the particular angle of heel*. This is true for all floating objects of cylindrical form; and thus it matters not how great may be the angle of heel, it is always found that the immersed wedge, L M *l*, is equal both in shape and volume to W M *w*, and also that their centres, P and K (see figure), are at equal distances, *x*, from the vertical line through B′. Knowing this, we can proceed to ascertain the whole range* of stability for our cylindrical vessel. The calculations for the levers of stability will be made at every 10° of heel.

A very simple method of illustrating the levers of stability for cylindrical vessels (and one which the reader might well try for himself, thereby proving by measurement the accuracy of the calculation) is as follows:—Cut a piece of cardboard circular in shape, and mark upon it in black dots the positions of the metacentre, the centre of buoyancy, and the centre of gravity (1 foot below the metacentre) in the upright condition. Loosely attach the cardboard to a flat board, placed vertically by means of a screw through the point indicating the metacentre, so as to be free to revolve. Over the head of the screw loop a thin length of cord, and to the other end attach a button or round piece of lead, so as to exactly cover the centre of buoyancy. Knot another piece of cord, and pass it through the back of the cardboard at the point indicating the centre of gravity, and at an indefinite length hang another button or weight. When upright, the two cords will hang together, but immediately the cardboard diagram is inclined the cords will separate, and the perpendicular distance between them represents the lever of stability. By revolving

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* By *range* is meant the extent of the inclination from the upright osition to the angle at which a ship's righting force vanished.

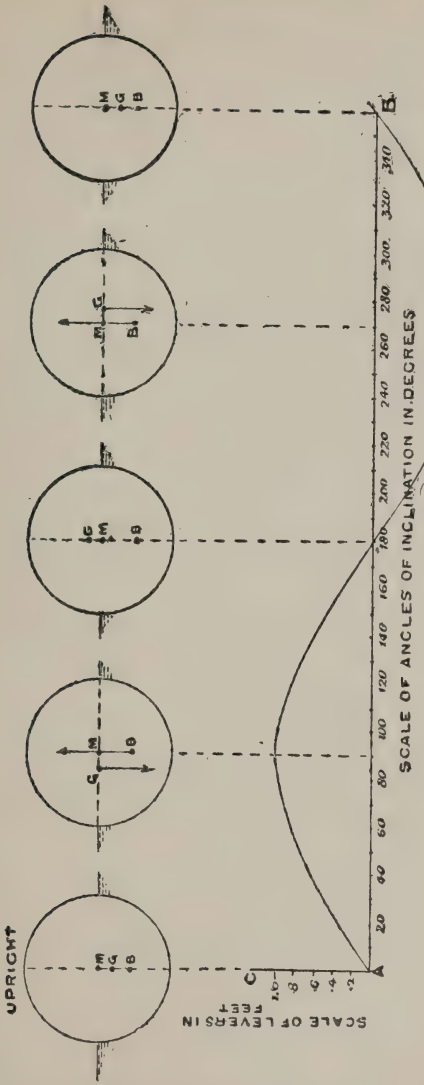

FIG. 79.—CURVE OF STABILITY.

the diagram at intervals it will be found that the levers measure according to the calculation G M × sine of angle of heel = lever of stability. [*Note.*—G M = 1 foot.]

Lever at 10° = 1 × sine of angle of 10° ·1736 = ·17
,, 20° = 1 × ,, 20° ·3420 = ·34
,, 30° = 1 × ,, 30° ·5000 = ·50
,, 40° = 1 × ,, 40° ·6427 = ·64
,, 50° = 1 × ,, 50° ·7660 = ·76
,, 60° = 1 × ,, 60° ·8660 = ·86
,, 70° = 1 × ,, 70° ·9396 = ·93
,, 80° = 1 × ,, 80° ·9848 = ·98
,, 90° = 1 × ,, 90° 1·000 = 1

To Construct the Curve of Stability (see Fig. 79).—Draw the horizontal line A B, and upon it at regular intervals mark off spaces, each indicating 10° of heel. The 10° spaces may be further subdivided into tenths, each representing 1° interval. From the point A draw the vertical line A C, and upon this line construct a scale of levers of stability, each space representing ·1 of a foot. Using the scale A C set up at the 10°, 20°, 30°, &c., intervals, their corresponding leverages, ·17, ·34, ·50, &c., and through all these points run a curve. By means of this curve, leverage at any intermediate angle of heel can now be readily measured. In the figure before us, we see by the diagram that the righting lever of stability steadily increases up to 90°, where it attains its maximum length, after that it gradually decreases exactly opposite to the way in which it increased until at 180° it vanishes altogether. The lever then begins to grow again, no longer a righting one, but an upsetting one, and it continues to increase up to 270°, where it is longest. After that, it again diminishes, until, when a whole revolution has been made at 360°, the vessel once more becomes stable.

But the question may be asked—How comes it that for vessels of ship form the vertical line through the centre of buoyancy only intersects the centre line of the ship at the metacentre for small angles of heel up to 12° or 15°, and at larger heels usually does not? The reason is simply this:—

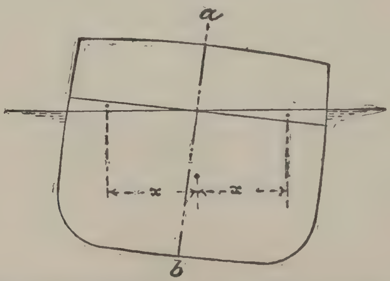

Fig. 80.—Wedges of Immersion and Emersion practically equal Sectors of the same Circle for Small Angles of Inclination.

The wedges of immersion and emersion of an actual ship for *small angles* of heel are practically sectors of a circle, and thus resemble the wedges with which we have just been dealing, in the vessel of cylindrical form, the wedges being exactly equal in volume, and practically identical in shape, with their respective centres at practically equal distances (x) from the vertical line through the centre of buoyancy (Fig. 80). So long as these conditions remain unaltered, the vertical line through the centre of buoyancy, at whatever angle the vessel may be inclined, will always intersect the line *a b* at the metacentre, and when such is the case, the distance M G multiplied by sine of angle of heel will give the lever of stability, G Z. But in vessels of ordinary ship form when inclined to large angles of heel, the wedges of immersion and emersion, although exactly equal to each other in volume, are dissimilar in shape, with their centres at quite unequal distances from the centre of buoyancy.

Metacentre Curves.—When this is the case, the vertical line through the centre of buoyancy does not intersect the line *a b*, Fig. 80, at the metacentre.* For large heels the position of the point M (originally the metacentre for the upright condition) is more difficult to ascertain, and is, therefore, discarded in present practice in determining the range of stability. Now, although it is advisable for a seaman to thoroughly understand displacement, buoyancy, the metacentre, and the principles governing and affecting the same, yet it is not necessary for him to enter into the mathematical method of calculating the same, for when these matters are understood, every necessary information about their values may be supplied to him in the form of curves, by the shipbuilder or naval architect who designs his vessel. Thus we have shown in Figs. 3, 5, 15, and 16 curves of displacement, curves of "tons per inch," and also curves of centres of buoyancy. Since these quantities are always the same at particular draughts, all that the seaman requires are the curves themselves, the knowledge of their value, and how to read them. The same applies to the metacentres. These also are fixed points for each draught for the vessel in the upright position, and, as we have shown, for small angles of heel. We shall now proceed to give an illustration of such a curve, and show how it is constructed and read.

The principle of the calculation for the metacentre of a vessel at a particular draught is the same as for a box, except that on account of the varying shape of the waterline, a slight modification has to be made, to find the moment of inertia of the waterline, *which, divided by the displacement at the particular draught, gives the height of the metacentre above the centre of buoyancy.* So that, first of all, we require the positions of the centres of buoyancy. In Fig. 15 a curve of centres of buoyancy is given for a certain vessel. This we shall transfer to Fig. 81, and set off the metacentres for the same vessel.

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* The metacentre is a term which ought only to be applied to the point M so long as it is constant in position, which is only for small angles of inclination.

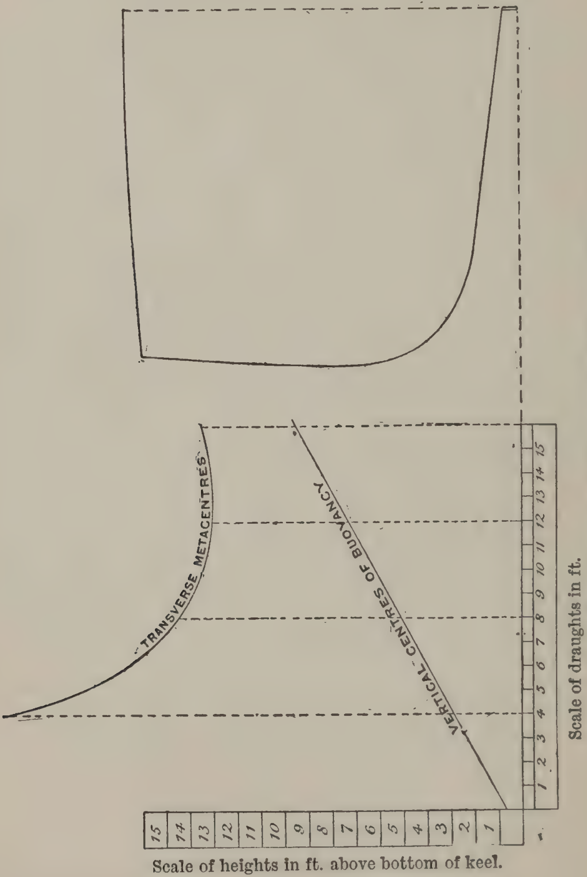

FIG. 81.—CURVE OF TRANSVERSE METACENTRES.

The metacentres, as calculated, were as follows :—

At 4 feet draught, 19·0 feet above centre of buoyancy.
,, 8 ,, 9·2 ,, ,,
,, 12 ,, 5·75 ,, ,,
,, 16 ,, 4 ,, ,,

At the point in the horizontal scale of draughts, representing 4 feet draught, draw a vertical line intersecting the curve of centres of buoyancy, and extending above it. Using the vertical scale of feet at the side, set up the height of the metacentre above the centre of buoyancy (19 feet), which shows the position of the metacentre to be 22 feet above the bottom of the keel. The same process is performed at the other waterlines, and when all the points representing the metacentres have been set off, a curve is run through them, which is that required, and enables us to read off heights of metacentres at any draught.

Unlike the centres of buoyancy and metacentres, the centre of gravity is not a fixed point except in certain conditions, and, therefore, cannot be supplied to the ship's officer. Every variation in the arrangement of weight or cargo, whether it be a yacht or cargo steamer, will affect the position of the centre of gravity, since, as we have already observed, the centre of gravity is the centre of weight. So that about the only conditions in which the centre of gravity may be relied upon as being a point capable of being specified in position beforehand are—(1) when the vessel is light, with bunkers empty, and no stores on board, and (2) when the bunkers are full, the boilers full, and all stores on board. To know the position of the centre of gravity in these conditions, is practically all that is required for yachts, whether they be sailing or steam, as these are about the only conditions in which they float. But for vessels carrying miscellaneous cargoes, perhaps wheat on one voyage, cotton on another, coal on another, and so on, the centre of gravity may possibly after loading seldom occupy the same position twice in succession, so that it becomes advisable to ascertain the metacentric height under certain conditions of loading. We shall, therefore, endeavour to show how the ship's officer may determine the metacentric height himself by finding the position of the centre of gravity.

How to find the Metacentric Height and the Position of the Centre of Gravity.—Perhaps some reader is imagining that the method will be that described in the Chapter on *Moments*, and it is quite true that the centre of gravity could be found by striking a horizontal line at the bottom of the keel, and multiplying each individual weight constituting the ship and the cargo—shell plating, frames, floors, decks, beams, masts, stores, cargo, engines, boilers, winches, windlass, and the host of other items, and dividing the sum of the moments by the sum of all the weights, the result being the height of the centre of gravity above the horizontal line. If carefully done, the method would be all very well, but the immense labour entailed must be evident to every reader. Happily, an accurate, as well as a very simple method may be adopted, by means of which the centre of gravity can be determined in a very short time by experiment. The day chosen should be as calm as possible. The vessel lying either in dock or river, should be moored only over stem and stern; no ropes abeam, and, if possible, with what breeze there may be, blowing directly fore and aft, so as to lend no assistance in heeling the vessel. Place a known weight with its centre over the centre line of the vessel, as near as possible to midships, and capable, when afterwards moved to the port or starboard, of inclining her 5° or 6°.

This weight may consist of anything heavy enough in its nature, and the centre of which and its weight can be accurately determined. Pig iron * may be conveniently used, or blocks of ballast iron, &c. These should be carefully ranged over as little space, according to the size of the vessel, as possible, and may weigh from 1 ton or less, to perhaps 15 or more tons.

This part of the operation having been carried out, the next thing to do is to carefully note the draught at which the vessel is floating. Let it be, say,

$$\left.\begin{array}{l}\text{13 feet 6 inches forward}\\ \text{14 feet 6 inches aft}\end{array}\right\}\text{a mean draught of 14 feet.}$$

This, on the displacement scale belonging to the vessel, reads 1,400 tons (see Fig. 3). At the centre line of the vessel suspend two plumb lines, one forward, and the other aft. Let both lines hang freely, and mark clearly a definite length on each of them, measuring from the point from which each one hangs, in our case, say, 8 feet. Great care should be taken to see that the lines hang perfectly plumb on the centre line of the ship. Having carefully arranged all this, we can now proceed with the experiment.

Let the weight of (say) 12 tons be moved from the centre of the vessel, first to starboard, as far as possible, in our example, say, 14 feet. This distance of 14 feet is measured from the centre of the weight when it was on the centre of the vessel to the centre of the weight when afterwards moved to starboard. Having done this, on going to the plumb lines it is found that by the fore one a deviation of (say) 5½ inches has occurred on the length of 8 feet, but on going to the aft one the deviation is found to be 6 inches. The weights should now be carried to the port side, and placed at the same distance as on the starboard side, 14 feet from the centre line of the ship. On going again to the plumb lines it is found that by the fore one 6¼ inches deviation has occurred, and 5¾ inches by the after.

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* A reliable and most convenient method is to fit a large fresh water tank on each side of the ship, and use the weight of water in this (if sufficient) for inclining purposes.

If all these be added together and divided by 4, we shall have the mean deviation :—

Port forward = 6¼
Port aft = 5¾
Starboard forward = 5½
Starboard aft = 6

4)23½

5·875 inches. Mean deviation.

Having obtained this result, the practical part of the experiment is now finished, the remainder being a matter of simple calculation. Three results have to be found.

1. *The distance the actual centre of gravity has moved to one side.* Perhaps some reader is saying, "but the centre of gravity has not been found." True, nevertheless we can find how far it has moved in the direction of the shifted weight. According to our study of moments in Chapter II., the rule is:—*Multiply the weight moved by the distance it is moved, and divide the result by the total weight.*

Weight moved = 12 tons.
Distance moved = 14 feet, and the total weight equals the displacement, which was found to be 1,400 tons.

$$\frac{12 \times 14}{1{,}400 \text{ tons displacement}} = 0{\cdot}12$$ foot distance the centre of gravity has moved in a line, parallel to the line joining the centres of the weight, in its original and in its new position.

2. The next thing to be done is to find the *cotangent of the angle to which the vessel has been inclined.* This is arrived at by *dividing the length of the plumb line in inches by the mean deflection of the plumb line at that length in inches.*

$$\frac{8 \times 12}{5{\cdot}875} = 16{\cdot}3 = \text{natural cotangent of angle of inclination.}$$

Although it is not needed in this calculation, still by referring to the table of cotangents at the end of the book, it is seen that the vessel has inclined to a mean angle of $3\frac{1}{2}°$.

3. The last part of the operation is to find *the metacentric height*, or the distance from the centre of gravity to the metacentre. This is done by *multiplying the shift of the centre of gravity by the cotangent of the angle of heel.*

$0{\cdot}12 \times 16{\cdot}3 = 1{\cdot}95$ feet, distance of metacentre above centre of gravity.

This result is the metacentric height of the vessel in its present condition—that is, with the weight used for heeling upon the upper deck. Now it is not likely that this weight will be carried in this position when the ship goes to sea. Should the weight be placed on board simply for the experiment, with the intention of placing it ashore afterwards, a correction must be made in the metacentric height, for it is evident that the weight being as we now find it, say, 8 feet above the centre of gravity, its effect is to raise the centre of gravity higher than it would be were the weight not there. Therefore, by taking the weight away, the centre of gravity must be lower. Then *weight removed, multiplied by its distance from the centre of gravity, and the result divided by the total weight*, which must be reduced by the removal of the weight, will give us the *distance the centre of gravity has lowered.*

$$\frac{12 \times 8}{1{,}400 - 12} = \frac{96}{1{,}388} = 0{\cdot}06 \text{ foot} = \text{how much centre of gravity is lowered.}$$

Thus, after the removal of the weight, the centre of gravity is $1{\cdot}95 + 0{\cdot}06 = 2{\cdot}01$ feet below the metacentre.

But suppose the weight used for heeling is one which is intended to be kept on board, being perhaps part of the ballast iron in the case of a yacht. Then, by lowering the weight into the hold again, the effect must be to lower the centre of gravity, and we proceed as in the previous case. (Weight × distance moved) ÷ displacement = distance centre of gravity has lowered.) Measure the distance from the centre of the weight on deck to its centre in the new position it will occupy in the hold, say, 15 feet. Then,

$$\frac{12 \times 15}{1{,}400} = 0{\cdot}12 \text{ foot distance centre of gravity is lowered.}$$

Therefore the corrected metacentric height is

$$1{\cdot}95 + 0{\cdot}12 = 2{\cdot}07 \text{ feet.}$$

Having become acquainted with the points known as the centre of buoyancy, the metacentre, and the centre of gravity, and to some extent the causes affecting them, and having given some attention to the wedges of immersion and emersion when the vessel is inclined, we are now more capable of pursuing our study of the subject, and of endeavouring to understand how the levers and range of a vessel's stability are affected under greater angles of heel.

Valuable as a knowledge of the metacentric stability (that is, stability at very small angles of heel) of a vessel may be under certain circumstances, yet *it alone is no safe criterion of a vessel's resource of safety*, when exposed to severe weather and subject to excessive heeling forces.

For example, in the loaded condition one vessel might have a metacentric height of, say, 1 foot, which for small angles of heel would generally give good righting force, but for greater angles of inclination the righting lever might rapidly decrease and soon vanish altogether; while another vessel, with perhaps only 6 inches metacentric height, and possessing small righting force for small angles of heel, might yet have a very long range of stability and good righting force at greater angles of inclination.

It thus becomes evident that further investigation is necessary, and we have yet to discover those features in a vessel's design, condition, &c., which so powerfully influence her stability under all angles of heel.

No.	Dimensions.* L. B. D. in Feet.	Freeboard in Feet and Inches		Centre of Gravity from bottom in Ft.	Metacentric Height in Feet.	Remarks.
1	100 × 12 × 10	5	0	6·3	– ·1	Showing effect of increase in beam, other dimensions remaining unchanged.
2	100 × 15 × 10	5	0	6·3	·57	
3	100 × 20 × 10	5	0	6·3	2	
4	100 × 25 × 10	5	0	6·3	3·9	
5	100 × 30 × 10	5	0	6·3	6·2	
6	100 × 20 × 10	1	0	6·3	2	Showing effect of increase in freeboard, other dimensions remaining unchanged.
7	100 × 20 × 10	1	6	6·3	2	
8	100 × 20 × 10	2	0	6·3	2	
9	100 × 20 × 10	4	0	6·3	2	
10	100 × 20 × 10	8	0	6·3	2	
11	100 × 20 × 10	1	6	8·05	·25	Showing effect of variations in position of centre of gravity, dimensions remaining unchanged.
12	100 × 20 × 10	1	6	7·3	1	
13	100 × 20 × 10	1	6	4·3	4	
14	100 × 20 × 10	1	6	2·3	6	
15	100 × 12 × 10	1	6	6·3	– ·1	
16	100 × 12 × 10	1	6	5·3	·9	
17	100 × 30 × 10	1	6	6·3	6·2	
18	100 × 30 × 4	16	0	14·5	6·2	

* L = Length; B = Breadth; D = Draught.

To treat of this effectively by means of actual ship stability data, would necessitate such a graduated variety of vessels as to make such a task a very laborious one. However, this difficulty is easily surmounted. Our purpose will be served by using vessels of box shape, which, while simpler in form than actual ships, are nevertheless capable of lending themselves to the main features we wish to illustrate, and of proving the principles it is desired to make prominent. The three great factors upon which the stability of any floating object depends, whether it be

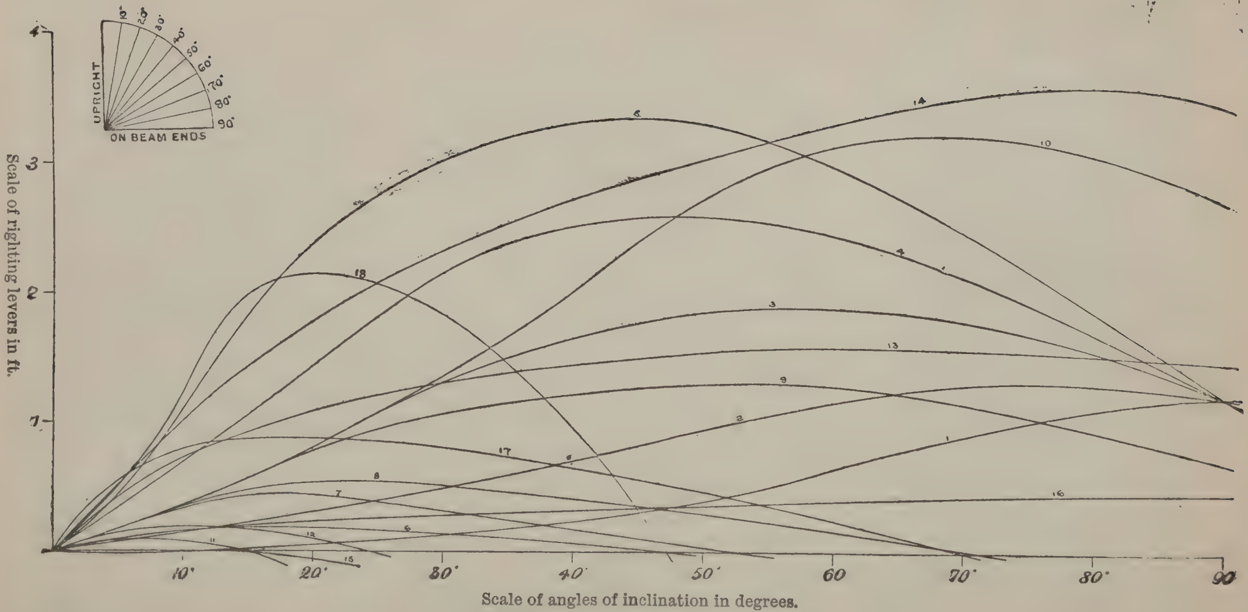


Fig. 82.—CURVES OF STABILITY.

of ship or box form, are *beam*, *freeboard*, and *position of centre of gravity*. By means of a series of box vessels, the particulars of which are given in the table (p. 123), and the curves of stability in Fig. 82, the endeavour will be made to reveal the importance of each.

1. **Effect of Beam.**—Vessels, numbers 1, 2, 3, 4, and 5, with the curves of corresponding numbers, will serve for reference and examples in this case. Here we have five vessels, each 100 feet long, 10 feet draught, 5 feet freeboard, and with beams of 12, 15, 20, 25, and 30 feet respectively. In each case we have imagined the centre of gravity to remain stationary at 6·3 feet from the bottom of the box, for the depth and draughts being assumed to remain the same in each vessel, it is quite reasonable to take it for granted that no change would occur in respect to the position of the centre of gravity.

It has already been shown, earlier in this chapter, that increase of beam raises the metacentre. This has, therefore, happened in the examples with which we are dealing, the result being a metacentric height of – 0·1, ·57, 2, 3·9, and 6·2 feet respectively.

Let us examine the curves of each of these vessels, and see what can be gathered from them.

Curve No. 1 commences with the metacentre 0·1 foot *below* the centre of gravity. In this condition the vessel is incapable of floating upright. Will she capsize? The curve answers the question most emphatically that she will not. If undisturbed she would take a slight list and then lie at rest. If forcibly inclined, the righting lever of stability would continue to grow in length, until, when on her beam ends (90° on curve), she has barely attained her maximum stability.

There is, however, nothing to elate one very much in the fact that a vessel has splendid stability at 90° of inclination, for every seaman knows that long before that angle is reached, it would be impossible to stand upon or work such a ship, and, moreover, weights on board which are considered as permanent and fixed would be on the move, and then most disastrous results would inevitably ensue. If the levers of stability are good up to 50° or 60°, and even then are decreasing and vanish altogether at 90°, not much fear need be entertained, for rolling to angles of even 30° or 40° on each side is considered very excessive.

Had we been guided in this particular case entirely by the metacentric height, the conclusion might have been come to that her condition is much more serious than it actually proves to be. Certainly the vessel is too tender; but what is needed is either ballast of some kind in the bottom, if the vessel is not down to the load waterline, or else a re-arrangement of the cargo so as to bring the heavy weights lower, and thus increase the metacentric height. Either of these methods would add immensely to the improvement of the vessel's condition. Further observations on this type of vessel are made at a later stage, in the remarks on "Rolling" and "Behaviour at Sea."

Curve No. 2.—The difference between this vessel and the previous one is, that owing to an increase of 3 feet in the beam the metacentre has been raised, and now the metacentric height is 0·57 foot. The curve shows longer levers of stability up to 90° of heel, where it crosses Curve No. 1. The vessel is therefore stiffer, and has greater righting force up to this point, but her maximum lever of stability is reached sooner than in the foregoing vessel.

Curve No. 3.—The beam is now 20 feet, giving a higher metacentre, and a metacentric height of 2 feet.

Curve No. 4.—Here the beam is 25 feet, with a higher metacentre, and a metacentric height of 3·9 feet.

Curve No. 5.—In this case the beam increasing to 30 feet, the metacentre continues to rise, and the metacentric height attains 6·2 feet.

Let us see what information can be gathered from these curves for similar vessels increasing in beam only.

First. With every increase in beam, and consequent increase in the metacentric height, the successive curves rise steeper and steeper, indicating greater stiffness and resistance to heeling.

Second. Each successive curve reaches a greater height than its predecessor, giving a longer maximum lever of stability, and, consequently, a greater righting moment.

Third. In each successive curve the maximum lever of stability is reached at a smaller angle of inclination.

Fourth.—In each successive curve the lever of stability vanishes at a smaller angle of inclination.

Judging from these curves, we might at first be inclined to give the entire credit of the great growth in the lengths of the righting levers in each successive curve to the increased metacentric height resulting from the increased beam; but a further comparison of curves will assist us in arriving at a more correct conclusion.

2. **Effect of Freeboard.**—*Curve No.* 6.—The vessel represented by this curve has the same length, breadth, draught, metacentric height, and height of centre of gravity above the bottom of the keel as No. 3. Instead of 5 feet freeboard she has only 1 foot. Mark the effect in the curve. Instead of the splendid sweep of No. 3 reaching its maximum lever of 1·9

feet at about 60° of inclination, and vanishing at considerably past 90°, No. 6 has never more than a lever of 0·2 foot, and that at the angle of 20°, the curve vanishing altogether at an angle of less than 50°.

Curve No. 7 is for a similar vessel, with 1·5 feet freeboard.
,, 8 ,, ,, ,, 2 ,, ,,
,, 9 ,, ,, ,, 4 ,, ,,
,, 10 ,, ,, ,, 8 ,, ,,

Let us gather again what these latter curves indicate.

First. Even good beam with good metacentric height, unless combined with suitable freeboard, is no guarantee for either a good range or good levers of stability. This is proved by a comparison of Curves Nos. 6 and 7 with Curve No. 3, and comparing also No. 17 with No. 5. These two latter are also identical vessels, with the exception of the freeboard, which is 1 foot 6 inches in the former and 5 feet in the latter. The great difference in the curves, which can only be attributed to the difference in the freeboard, is very apparent.

Second. Increase in freeboard with undiminished metacentric height, increases not only the length of the levers, but the maximum lever in each case is at a greater angle of inclination, and the range of stability is lengthened out also. Curves Nos. 6, 7, 8, 9, and 10, with their increasing freeboard, prove this, each of the first four in its turn approaching No. 3, until No. 10, with the great freeboard of 8 feet, far surpasses it in both maximum levers of stability and range.

It may be all very well to make the statement that freeboard has this and the other effect upon a vessel's stability; but some reader may be asking the question "How is it that freeboard is capable of producing such an effect?" An endeavour to explain this will be made by the aid of the following graphic illustration (Fig. 83).

Figs. i. and ii. are the vessels in the table, Nos. 8 and 3 respectively. They are similar to each other, except that i. has 2 feet, and ii. 5 feet freeboard. Floating in the upright condition they have exactly the same metacentric height, 2 feet. Let Fig. i. be heeled until the deck edge is down to the level of the water, as shown in Fig. iii., the angle of inclination being 10°. To find the lever of stability we must turn our attention to the centre of buoyancy. Let Fig. x. represent the buoyancy of the vessel, which corresponds in every respect to the immersed part of Fig. iii. The centre point in Fig. x. is B, and this is the centre of buoyancy. By transferring the position of B to Fig. iii., we see its position in relation to the centre of gravity. The distance between the vertical lines

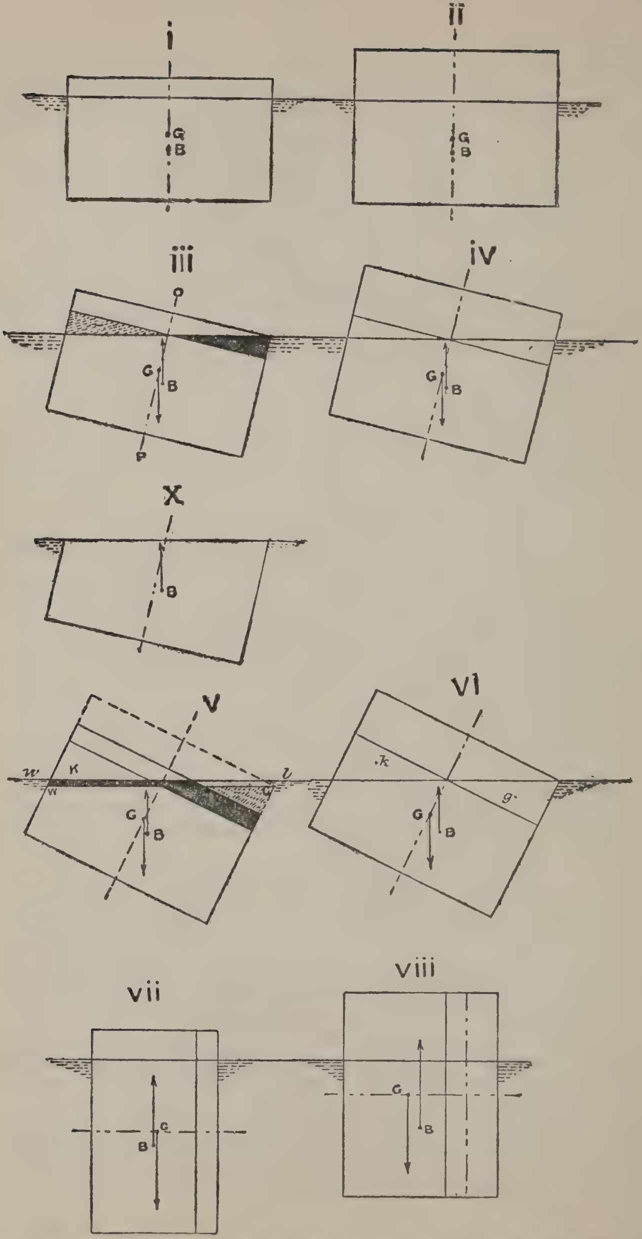


FIG. 83.—SHOWING EFFECT OF FREEBOARD ON STABILITY.

through these points is the lever of stability, and since it intersects the centre line, O P, above the centre of gravity, it is a righting lever. Although the shape of the buoyancy has altered in form under the inclination, owing to the transference of the wedge of buoyancy shown by the hatched lines, to the other side of the vessel, indicated by a black wedge, yet its volume is unchanged. The centre of buoyancy, therefore, travels in the direction in which the buoyancy is transferred, just in the same manner as shifting a weight upon a lever, the distance in the case of the wedges being reckoned from centre to centre.

Turning to Fig. ii. with the greater freeboard, on inclining this vessel to the same angle 10°, her deck edge is still considerably out of the water (Fig. iv.). However, in this condition her form of buoyancy is similar to Fig. iii., simply because the wedges of immersion and emersion are identical in shape. The centre of buoyancy, therefore, occupies the same position, and it follows that the lever of stability must be similar to that in Fig. iii.

Let Fig. ii. be now heeled until its deck edge reaches the waterline, as shown in Fig. vi. The reasoning applied to Fig. iii. will apply in this case also—A wedge of buoyancy has been transferred from one side to the other, giving the form of buoyancy shown below the waterline, the centre of which is the centre of buoyancy, B. This point again shows the relation of the centre of buoyancy to the centre of gravity, and the lever of stability is found to have increased simply because a larger wedge has been transferred a distance of *k* to *g* (the centres of the wedges from each other).

Fig. i. at this angle of inclination shows a different state of affairs (see Fig. v.). There is certainly a wedge of emersion, but owing to the decreased freeboard, there cannot be a similar wedge of immersion. The dotted line indicates the boundary of the greater buoyancy of Fig. vi. Now, supposing Fig. v., when inclined, to float at the waterline W L with the wedge of emersion K, then there ought to be a wedge similar in volume immersed. But this cannot be, for the immersed wedge is deficient by the volume of the small wedge indicated by the hatched lines in the diagram. Now, the volume of the emerged part, of whatever shape, must equal the volume of the immersed part, and since the immersed wedge is deficient by the small wedge already referred to, this loss of buoyancy can only be regained by the vessel sinking to a deeper draught, thereby spreading the buoyancy of the lost wedge along the waterline, and thus causing the vessel to float at the new waterline *w l*. The black part in the figure shows the new immersed buoyancy. The important point is to find what effect this new immersed buoyancy will have upon the lever of stability. The more buoyancy that can be placed towards the side to which the centre of buoyancy has already begun to move, the further will this point be brought towards that side. Owing to the lower freeboard the loss of the hatched wedge of buoyancy has robbed the vessel of a most effective agent in bringing out the centre of buoyancy from the centre of gravity, and by placing this lost buoyancy along the waterline, a further check is made upon the outward movement of the centre of buoyancy, and the tendency is to draw it back again; hence the decreased lever of stability, as compared with Fig. vi. Passing now to the conditions shown in Figs. vii. and viii., we find these vessels heeled to an angle of 90°. The centre of buoyancy can easily be determined in these cases. For Fig. vii. it will be *half the distance from the bottom* (not the bottom of the figure, but the bottom of the ship) *to the deck*, which is $\frac{10 + 2}{2} = 6$ feet, and the centre of gravity being 6·3 feet, the result is an upsetting or capsizing lever of 0·3 foot. Fig. viii., however, has the advantage of the buoyancy afforded by the additional freeboard shown beyond the dotted line. This naturally tends to draw out the centre of buoyancy, and its position now is $\frac{10 + 5}{2} = 7{\cdot}5$. $7{\cdot}5 - 6{\cdot}3 = 1{\cdot}2$ righting lever

The foregoing remarks, with a little study of the figures themselves, will leave little doubt in the mind of the reader of the importance of freeboard as a factor in affecting stability.

3. **Effect of Position of Centre of Gravity.**—Let us take our final illustration, and note the effect of obtaining metacentric height, not by means of increasing the beam, and thereby raising the metacentre, but by retaining the same beam and same position of metacentre, and lowering the centre of gravity.

This may be done to a considerable extent in merchant steamers, in loading miscellaneous cargoes, by keeping the heavy weights low, but to a very much greater extent can it be done in yachts, where the centre of gravity can almost be placed wherever desired by means of permanent ballast.

Curves Nos. 11, 12, 7, 13, and 14 are for vessels 100 feet long, 20 feet broad, and 10 feet draught, with 1 foot 6 inches freeboard, the metacentre being, therefore, at the same height from the bottom of each vessel—viz., 8·3 feet. The only difference between them is in the height of the centre of gravity.

For No. 11, the centre of gravity is taken at ·25 foot below the metacentre.
" 12, " " 1 " "
" 7, " " 2 feet "
" 13, " " 4 " "
" 14, " " 6 " "

The effect of this alteration in the position of the centre of gravity is shown by the curves. *First, at a particular draught,* by every downward movement of the centre of gravity, thereby causing an increase in the metacentric height, both the levers and range of stability are lengthened. *Second*, each curve rises more steeply than its predecessor, indicating greater stiffness.

We have already seen the effect of beam upon stability. Suppose 10 feet be added to the beam of a vessel identical in every respect with No. 14. The effect is to raise the metacentre, and give much greater metacentric height. But let the centre of gravity also be raised from 2·3 feet from the bottom of the vessel to 6·3 feet, the metacentric height being now 6·2 feet, the result is to give a vessel identical with No. 17. Nos. 14 and 17 differ now practically in beam only.

An error is sometimes made in a case like this, it being imagined that the broad vessel, even with the same metacentric height, is better than the narrow one of the same depth and freeboard. If the curves of these two vessels be compared, their stability is seen to be widely different, the narrow vessel possessing more stability in every respect than the beamy one, except perhaps a little at the beginning of the curve.

Now how does this happen? In the first place, the advantage of the increased metacentric height, which was obtained by the increased beam, was robbed from the vessel by raising the centre of gravity, and making the metacentric height similar in both cases. Perhaps some reader is still saying—Having made the metacentric height similar for both vessels, why are the curves not similar? This is just where the error is often made in depending upon the metacentric stability, which, as has been previously stated, is no guide for a vessel's range of stability, but only for small angles of inclination. Up to 7° or 8° these curves are approximately the same. For greater angles of inclination, we must turn our attention to the centre of buoyancy, and trace its movements in relation to the position of the centre of gravity.

In A and B, Fig. 84, no levers of stability are seen, since the vessels float upright and are perfectly stable, with the centre of gravity, centre of buoyancy, and metacentre (the last not indicated) in the same vertical line, *a b*. In Figs. C and D the same vessels are inclined to angles of 45°. It is now seen that the levers of stability in this condition are very different, that for the smaller vessel being much the greater. Both the centre of buoyancy and the centre of gravity, though chiefly the latter, are accountable for this result. Turning our attention first to the centre of buoyancy, we find that, in both Figs. C and D,

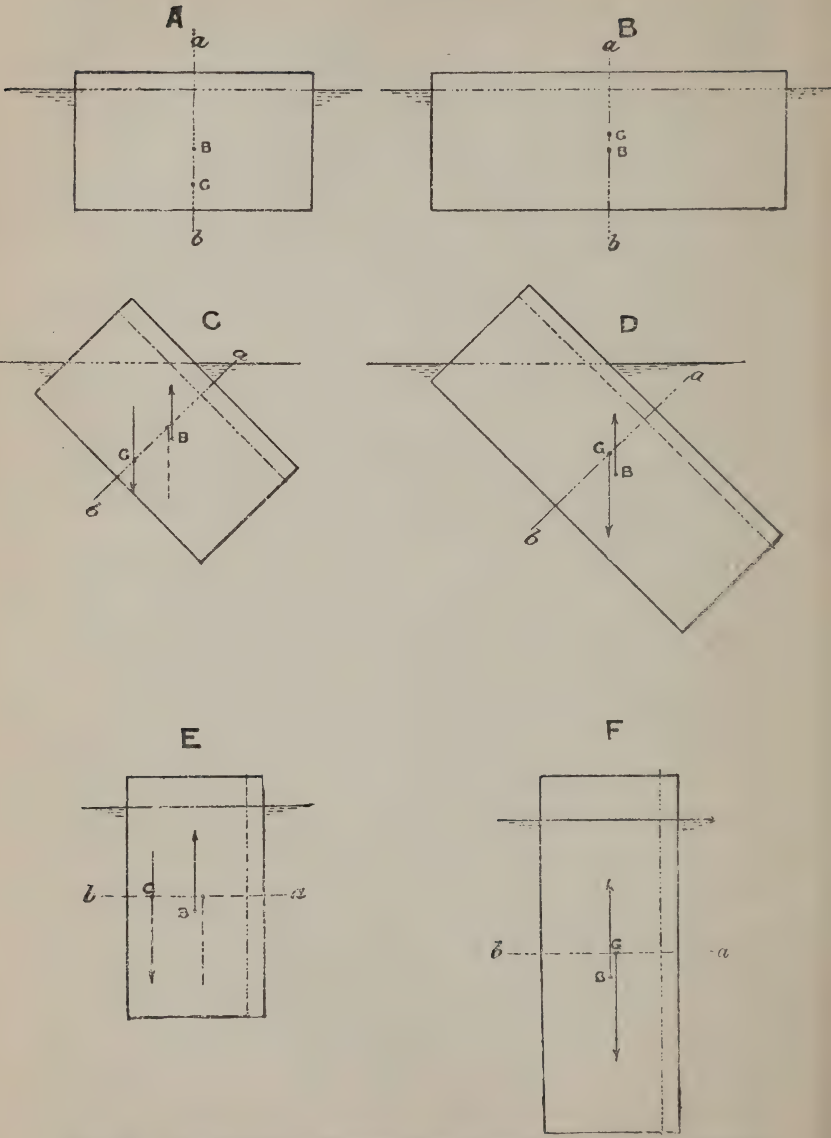


Fig. 84.—Comparison of Vessels with different Beams but similar Metacentric Heights.

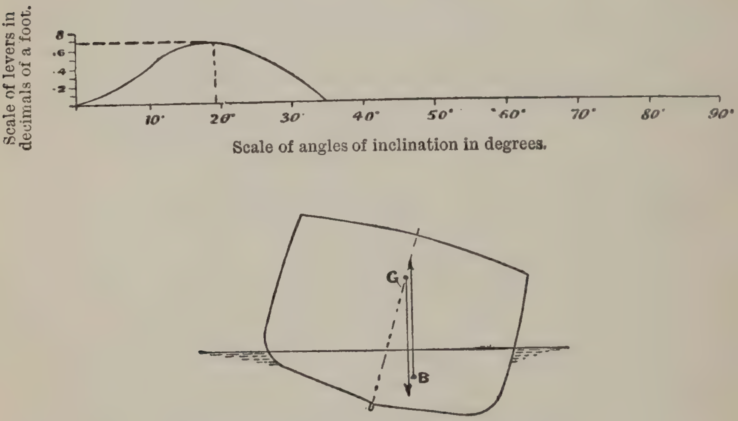
owing to the small freeboard in each case, the deck edge has become immersed when inclined to a very small angle. This at once checks the outward movement of the centre of buoyancy, though Fig. C, owing to its smaller beam, has the advantage to some extent, since greater inclination would be needed to immerse its deck edge than would be required for Fig. D.

Turning now to the centre of gravity in each case, we find here the chief factor in producing the great difference in the stability levers. It is first noticed that their difference in position from the bottom of each vessel on the line *a b* is very great, although the metacentric heights in the upright condition are practically identical. In Fig. B it was easy to get a good metacentric height, owing to the great beam, but in Fig. A the greatly reduced beam made it necessary to very much lower the centre of gravity, in order to get the same metacentric height. Hence the difference in their positions. It will also be observed that the *lower the position of the centre of gravity* is on the line *a b*, the *greater must be the righting lever of stability* (a glance at the figures will show this clearly), and on the other hand, the *higher the position of the centre of gravity* on the same line, the *smaller the lever.* This, then, accounts to a great extent for the difference in the levers of stability. So that even on their beam ends, at angles of 90°, we still find the narrower vessel (Fig. E) with a large righting lever, while the broader one, F, has actually an upsetting lever.

However, the case we have taken is certainly an extreme one for cargo or passenger vessels, for while in the broad vessel the position of the centre of gravity would very often be found high in comparison with the depth, in the narrow vessel, it would be impossible to load her and have the centre of gravity as low in comparison with the depth. Were the two vessels loaded in the same manner—that is, in relation to the vertical position of the weights of the cargo, the centre of gravity in both vessels occupying the same position from the bottom of the box—a vastly different result would arise. Let the centre of gravity of the narrow vessel be raised by the loading of cargo to the same position as in the broader one—viz., 6·3 feet from the bottom of the vessel. The dotted lines on the figures show the new vertical line through the centre of gravity of the narrow vessel, and curve No. 7 will show the whole range of stability. The tables are now turned against the narrow one, indicating much reduced stability. Hence the necessity of wisdom in loading, as in the latter case, the heavy weight of the cargo would have to be placed much lower in order to get anything approaching similar levers of stability for the two vessels.

But while the position of the centre of gravity at 2·3 feet from the bottom of the vessel for curve No. 14 is an exaggerated case for merchant vessels, it is by no means out of the way for sailing yachts, for in order to get great stiffness and long levers of stability, which are necessary to carry great sail area, especially with small beam, the method of bringing the centre of gravity very low by placing ballast either in the keel, or else as low as possible, has to be adopted.

Before leaving this part of the subject of stability, the reader is again warned against jumping to the conclusion that even a combination of good beam, good freeboard, and good metacentric height will always produce satisfactory stability. This has already been shown by the several box vessels and their curves, and will further be emphasised by a glance at the curve of stability, Fig. 85, which is for a sailing ship in a light condition. She has 41 feet beam, 2·9 feet metacentric height, and 17½ feet freeboard, the last of which is extremely great, and yet the curve of stability in this condition represents both short levers and very short range, this being attributable to the fact that, in the light condition, the heavy top weight of masts, spars, &c., brings the centre of gravity very high, and it has



Inclination showing maximum lever of stability.

Curve of stability for a sailing ship, 270 feet long, 41 feet beam, and 26 feet 3 inches depth, in a light condition, with about 112 tons of ballast on board. Metacentric height, 2·9 feet. Centre of gravity, 20½ feet above the top of the keel. Freeboard, 17½ feet.

Fig. 85.

already been pointed out that the higher the centre of gravity, the shorter are the levers of stability, and the sooner does the vertical line through the centre of buoyancy intersect the centre line of the ship below the centre of gravity, thereby creating a capsizing moment. The same vessel in her loaded condition, with only 5½ feet freeboard and 3 feet metacentric height, would have both immensely greater levers, and greater range of stability, because then the centre of gravity is much lower in its position.

In a box vessel, say, 20 feet deep, if the centre of gravity be at half the depth, the righting lever of stability must vanish at 90° of inclination, whatever be the freeboard, since in this condition the centre of buoyancy and the centre of gravity are in the same vertical line. If the centre of gravity be higher than half the depth, the levers will be shorter and the range less also, but if the centre of gravity be lower than half the depth, then the levers will be longer, and the range will extend beyond 90° of inclination. Now, all actual ships are not of box form, though it is granted that in some cases it is somewhat difficult to draw that distinction. Of two vessels of similar beam and depth, the one with most buoyancy in the upper half of her depth, being therefore most fined away at the bilge and bottom, can afford to have the centre of gravity the higher, and the nearer the box section is approached, the lower must be the centre of gravity.

The actual box ship is, therefore, the worst case, since it brings the centre of buoyancy into the lowest possible position; and, on the other hand, the vessel fullest at the waterline, and well fined away below, has its centre of buoyancy in the highest possible position, in which position the longest levers and the greatest range of stability are produced, other features in the design being favourable. It is thus impossible to stipulate a particular position for the centre of gravity applicable to all ships.

For a box-shaped vessel, if the centre of gravity is from about 0·5 to 0·6 of the depth from the top of the keel, with fair metacentric height, a fairly good range of stability may be expected, though the righting levers may be small under certain circumstances. For vessels of finer underwater form greater stability would be developed, and when the centre of gravity is less than 0·5 of the depth from the top of the keel, great stability may be anticipated.

Effect of Tumble Home.—In Fig. 86, let G be the centre of gravity, B the centre of buoyancy in the upright position, C D E the immersed wedge, and K the centre of the immersed wedge.

The greater the distance from the original centre of buoyancy, B, to the centre of buoyancy of the immersed wedge, K, as shown by the line P, the greater will be the effect in drawing the centre of buoyancy out from its original position. Let B′ be the new centre of buoyancy when inclined, and G Z the righting lever of stability.

Now, supposing a piece of the shape of the black wedge be cut off from the vessel, let us observe the effect upon the stability. Owing to the loss of this buoyancy when inclined, compensation must be made by apparently drawing upon the reserve buoyancy, and taking a layer off all along the waterline to the dotted line, simply because the wedge of immersion is now less than the wedge of emersion; and they are equalised by adding a layer to the wedge of immersion at C D, and deducting a layer from the wedge of emersion at W C.

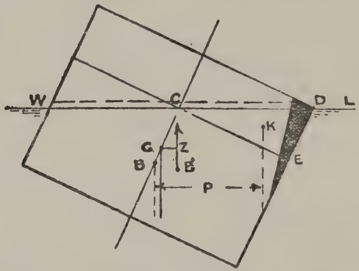
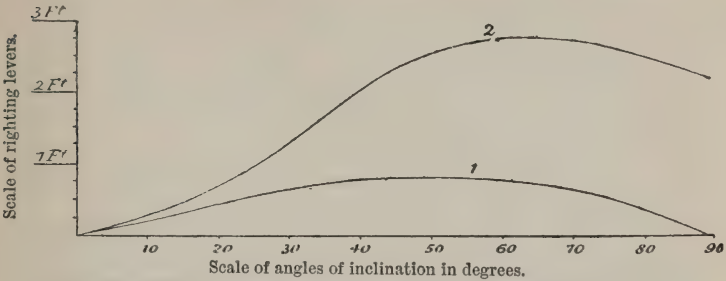


Fig. 86.—Effect of Tumble Home on Stability.

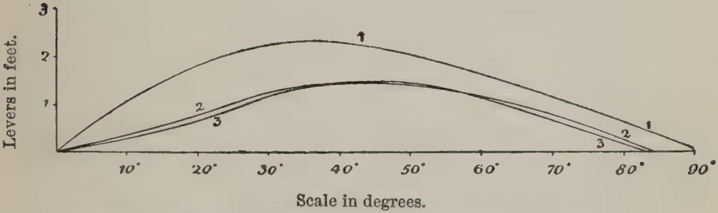
The centre of the immersed wedge, K, will have travelled towards the left of the figure, causing B′ to move in the same direction, and the layer of buoyancy along the waterline, W to C, will also have aided to produce this effect.

G Z will now have become shortened, which means reduced righting moment of stability.

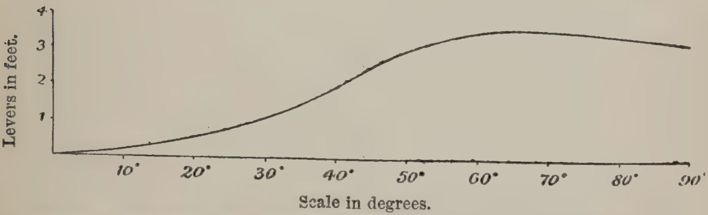
Taking the case of a vessel of ship form, we can easily see the application of the above illustration. Instead of carrying the sides up perpendicularly they are usually curved in, as shown in Fig. 72. This is known as *tumble home.* A valuable piece of buoyancy is lost; in fact, the very part of the wedge which is most efficacious in drawing out the centre of buoyancy from the centre of gravity is cut away. Thus in vessels of low freeboard, and especially if at the same time possessing narrow beam, the effect of much tumble home may be to assist in causing deficient stability in certain conditions. However, as it is not usual to give an ordinary mercantile vessel more than a few inches of tumble home at the main deck, the effect is not serious in the ordinary types of modern broad beamed cargo steamers.



Curves of stability for a cargo steamer—Length, 480 ft.; beam, 57 ft.; depth, 40 ft.
Curve No. 1, Light condition, metacentric height, 2·68 ft.
" 2, Load " " 3·67 "



Curve for a steamer 410 ft. long, 50 ft. 6 ins. beam, 32 ft. depth.
No. 1, Light condition, metacentric height (G M) = 11·06 ft.
No. 2, Loaded with homogeneous cargo, 7 ft. 6 ins. freeboard, G M 1·85 ft.
No. 3, Same as No. 2, with coal consumed. G M 1·58 ft.
Note.—1 ft. in the scale of levers in this figure is equal to 2 ft. for *No. 1 Curve.* The levers are thus only half length on this diagram.



Curve for a vessel 360 ft. long, 45 ft. beam, 30 ft. 1 in. depth. Metacentric height 1·48 ft

FIGS. 87, 88, AND 89 ARE EXAMPLES OF ACTUAL SHIP CURVES.

A point which is sometimes overlooked on the part of the owner or his representative in the design of a new vessel, is the value of sheer. That it adds to the appearance, gives valuable rising power, and tends to prevent the shipping of water over the stem and stern, must be clear to everyone.

But one of its best features is that it produces increased freeboard, the use of which has already been discussed.

Stability in different Types of Vessels.—As regards types of vessels best adapted to produce good stability when of suitable dimensions, and the loading properly carried out, those with most freeboard must come first.

Thus we have the *awning decker*, with its completely closed-in light superstructure between the main and awning decks, splendidly adapted for *carrying passengers* or light cargoes.

Next comes the *spar decker* with a stronger superstructure, and adapted for *carrying cargoes* of greater density with smaller freeboard in comparison with the awning decker.

Last, we have the strongest type of ship, the *two* or *three decker*. This is the *best deadweight carrier*, having least freeboard. Unfortunately, structural strength and stability are in no way related to each other, and thus, as statistics prove, especially the older types of these vessels, with their small beam to depth, and also small freeboard, have produced the most disastrous results, through lack of stability. A vessel which has found great favour among shipowners during late years, because of its special adaptation for certain trades, is the *raised quarter decker*, which is simply a modification of the strong two or three deck type previously referred to, and whose comparatively greater freeboard assists in producing more favourable stability.

Note.—Awning- and spar-decked ships are equally as strong as three-deckers in relation to the deadweight they carry at their respective load lines.

CHAPTER VI. (SECTION II.)

ROLLING.

CONTENTS.—Rolling in Still Water—Relation of Stiffness and Tenderness to Rapidity of Movements in Rolling—Resistances to Rolling—Danger of great Stiffness—Rolling among Waves—Lines of Action of Buoyancy and Gravity—A Raft, a Cylinder, and a Ship among Waves—Synchronism, how Produced and Destroyed—Effect of Loading upon Behaviour—Effect of Transverse Arrangement of Weights upon Rolling Motions—Alteration in Behaviour during a Voyage—The Metacentric Height—Fore and Aft Motions—Fore and Aft Arrangement of Weights.

Rolling.—After the consideration already given to the subject of stability, we are now able to proceed further, and observe the relation between stability and rolling at sea, and what means can be adopted to reduce the latter to a minimum.

Rolling is often spoken of as though it were a particular quality belonging to a ship. For instance, it is not uncommon to hear a ship described as a heavy roller; or another, as being very steady. A little investigation will show that it is not strictly correct to so characterise any vessel. At the same time, however, we shall see that the design of some vessels lends more encouragement to rolling than others; and, on the other hand, it is possible to a considerable extent to overrule even the influence of design, and make a vessel either steady, or specially inclined to heavy rolling, in spite of design.

Let us briefly enumerate the points we have already studied, which will help us.

First. If a vessel rolls under the influence of some external force, the power she possesses which brings her back to the upright is her stability.

Second. If a vessel has a great metacentric height, it follows that, at least for small angles of inclination, she possesses considerable righting moment, and the curve representing levers of stability will rise the more steeply the greater the metacentric height. Such a vessel is said to be stiff.

Third. If the metacentric height is small, the reverse of the previous case will be the consequence, the righting levers will be small for small angles of inclination, and the curve of stability will rise slowly.

The effect of metacentric height in relation to rolling is exactly the opposite to what one would at first imagine. The stiff ship with great metacentric height offering great resistance to inclination, is the very one which generally rolls most in a seaway; and the tender vessel, with small metacentric height and small resistance to heeling, is usually the steady one. How comes this? We shall be better prepared to answer if we make a few mental experiments upon a vessel for ourselves.

Rolling in Still Water.—Let us imagine a ship with large metacentric height and a fair range of stability to be lying in the dock. By means of some external force let the vessel be heeled over to, say, 10° of inclination, and held there. We know that the centre of buoyancy will have shifted into the centre of the new shape of displacement, and there is now created a lever between the vertical lines passing through the centre of gravity and the centre of buoyancy. It is, therefore, evident that the vessel possesses an amount of righting force exactly equal to the external heeling force required to so heel her, and by means of which, when the latter is removed, she will come to the upright. In this position the available righting moment will have disappeared, since the centre of gravity and the centre of buoyancy are again in the same vertical line. Moreover, the greater the metacentric height the greater the amount of available righting moment, and thus the more rapidly will she reach the upright position.

Resistances to Rolling.—Let us now free our vessel lying at the angle of 10°. The result is, that in the space of a few seconds she has reached the upright. But does she remain there? Not at all, for just as in the case of a pendulum in travelling from an angle of inclination to the vertical, an amount of energy of motion (*kinetic energy*) is accumulated, which carries her over to the other side, where again a righting lever is created acting in opposition to the last roll. Were there no resistance of any kind this process of rolling would be endless; but experience shows us that after a series of rolls, the vessel will come to rest. This is brought about by the united action of several kinds of resistance.

First. The *friction of the air* upon the exposed surface of the vessel.

Second. The *friction of the water* upon the immersed surface.

Third. Head resistance, caused by projections on the immersed surface.

Fourth. Wave resistance.

As the great object is to get a safe and steady ship, let us see how far it lies in our power to modify these resistances.

Nothing can be done to increase the air friction, unless it be by means of sail, which will certainly tend to produce steadiness. It would be an easy matter to make a rough skin upon a vessel; but this would deduct so enormously from the speed, that it is preferred to get the smoothest surface possible. In the third case, however, a very great deal may be done to produce steadiness by fitting projections in the form of keels or bilge keels. The day of doubt as to the efficiency of this means is past. Not only are naval experts agreed, but the testimony of every seaman who has experienced the efficacy of bilge keels, especially when fitted upon vessels which had previously been without them, is unanimous as to their great value in reducing both the number and angles of roll, or oscillations.

By an *oscillation* is meant *a complete roll* from port to starboard, and the time occupied to perform such oscillation is termed *the period of oscillation.* An example, taken from the experiments of the late Mr. Froude, upon the model of the war vessel "Devastation," will serve as an illustration in passing—

Number and Description of Bilge Keels.	Number of double Oscillations before Vessel was brought to rest.	Period of double Oscillation in seconds.
1. No bilge keels, ...	31½	1·77
2. One 21 inch bilge keel on each side,	12½	1·9
3. ,, 36 ,, ,, ,,	8	1·9
4. Two 36 ,, ,, ,,	5¾	1·92
5. One 72 ,, ,, ,,	4	1·99

In speaking of wave resistance, we do not refer to sea waves—for, as was formerly stated, the vessel upon which we are experimenting is supposed to be lying in a dock—but to waves created by the vessel in her rolling movements in the water. Such might at first appear to be very trivial, but to create such waves, even though very small, means an immense expenditure of energy, and this, therefore, must be deducted from the total available energy, which incites the vessel to roll. The combined effect of these agencies is to diminish the angle of inclination, and, finally, to produce extinction. A noteworthy point to be observed, as shown by the above table, is that for moderate angles of inclination the period is approximately the same for the larger as for the smaller oscillations. Thus we see that it is great stability which conduces to rapidity of rolling motion, though not necessarily to great angles of inclination.

Danger of great Stiffness.—The danger of very stiff vessels with good range of stability is, not that they will capsize, but by the severity of their movements that they will damage themselves by straining the structure and causing leakage, or by shaking their masts overboard, not at all an unheard-of occurrence, where broad-beamed sailing ships, owing to pure ignorance, have been ballasted in a manner producing enormous stiffness.

On the other hand, the vessel with the small metacentric height, when forcibly inclined to the same angle of 10°, and then set free, returns to the upright much more slowly, having shorter righting levers, and, therefore, less stored energy. The energy of motion acquired in returning to the upright is less, and adding to this the resisting agents, it follows that the angles to which she rolls, and the number of oscillations before coming to rest, will be reduced.

The nearer the immersed portion of any object approaches the shape of a circle, and the nearer the metacentre and the centre of gravity are together, the less power to regain the upright will it possess until we reach the minimum in the actual cylindrical type with the centre of gravity and the metacentre coincident. Vessels of this latter type possess no righting force at all, and thus, when inclined to an angle, they remain there, even though entirely free. A very small external force, therefore, will heel them, and turn the underside uppermost altogether.

Rolling among Waves.—Now the question arises, since the motion of rolling is so governable, is it better to have the steady type of ship with small metacentric height, or the stiff one with great metacentric height? But this we shall better answer if we first briefly consider her more complicated motions among waves, as thus far our considerations have dealt exclusively with vessels in still water. Here, however, peculiarities arise, and although the principles deduced from forced rolling in still water still hold good to a great extent, we shall find our ship behaving very differently at times from what we should imagine if we depended solely upon our knowledge of rolling in still water. In the first place, it is scarcely necessary to inform any reader who has ever noticed a piece of wood floating in the sea among unbroken waves, that it is not the mass of water composing the waves which moves onward, but the form only. A slight forward and backward motion of the floating object shows that the only movement of the wave water is slightly forwards and backwards. At a comparatively small distance below the surface of the water there is apparently no motion whatever. An old, though not strictly correct, illustration is that of wind blowing over a field of corn, causing a waving motion as the heads incline with the gusts of wind, and then rise again.

Raft.—As a complex form like a ship is a form more difficult to deal with than that of a flat floating piece of wood, let us examine, first, the behaviour of a small raft. In smooth water we know that owing to its great stiffness its oscillations are exceedingly rapid and its period very short, and that a condition of rest is soon obtained.

We have also noticed that when among wave water (Fig. 90) its deck is always parallel, and the mast perpendicular to the surface of that part of the wave upon which it is floating. It is therefore upright on the summit and in the trough of each wave, and its greatest angle of inclination is at about half the height of the wave where the slope is greatest. In this case the raft, being very small, behaves practically as though it were actually a particle of the surface wave water. Such agreement becomes less and less as the beam increases relatively to the length of wave, as it can no longer lie flat on the surface, or have the greatest angle of inclination where the wave slope is greatest, until at last, where exceptionally large beams are reached, as in the Czar of Russia's yacht "Livadia" (153 feet), the vessel no longer takes of the motion of a small raft at all, but maintains a comparatively horizontal deck, as in Fig. 91.

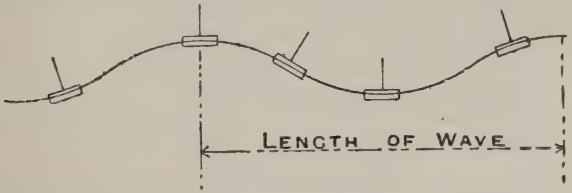


FIG. 90.—BEHAVIOUR OF A SMALL RAFT AMONG WAVES.

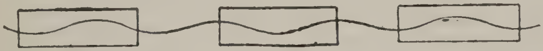


FIG. 91.—BEHAVIOUR OF A LARGE RAFT AMONG WAVES.

The longer the waves are in comparison with the breadth of such a vessel, the greater inclination she would reach in endeavouring to follow the angle of the wave surface. But in a short sea she would be practically steady.

Cylinder.—Let us take as another example a vessel of the cylindrical type.

In Fig. 92 we see the object as it would float in smooth water. Being of wood, and of equal density throughout, the centre of gravity is in the centre, as is also the metacentre.

The centre of buoyancy is in the same vertical line through this point, and the object floats at rest, as it will do at any angle of heel, since it never has any stability; a state which can only exist when there is no righting lever, the vertical lines through the centre of gravity and the centre of buoyancy always coinciding.

In Fig. 93 we see the same object among waves, and on a wave-slope. Let us examine its condition now.

From observation every reader knows that no revolving or heeling motion occurs. The line *a b* remains vertical, and the waterline varies from R S, when floating in still water, or on the crest, or in the trough of the wave, to X Y, the greatest wave-slope. But on examining the object on the wave-slope, it is found that the centre of buoyancy has shifted into the centre of the immersed part. If we drop a vertical line through the centre of gravity and through the centre of buoyancy, we see that these points are no longer in the same vertical line, but that a distance exists between them. If this distance represents the length of the lever of stability, the vessel cannot remain in this condition without making some effort to bring the centre of buoyancy and the centre of gravity into the same vertical line, which effort must incline the vessel more or less. But observation proves that such is not the case, for the object makes no movement to the one side or the other, the only interpretation of such behaviour being that no lever whatever exists, and that the downward force of the weight of the ship and the upward force

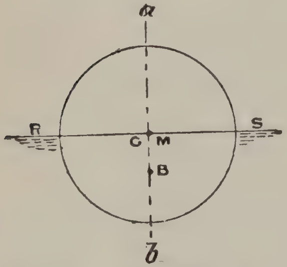


Fig. 92.—Behaviour of a Cylindrical Vessel in Smooth Water.

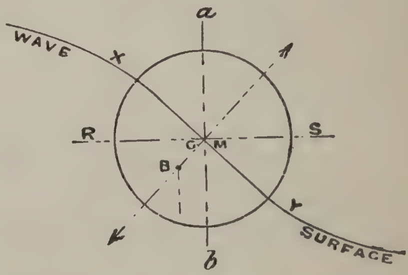


Fig. 93.—Behaviour of a Cylindrical Vessel among Waves.

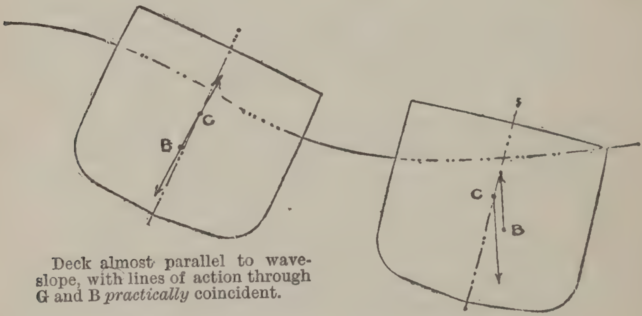
of buoyancy are evidently being subject to other forces causing them to act differently from the manner in which we have been accustomed to consider them in still water. It is just on this point where many of those, whose knowledge of the subject of stability, &c., is very limited, are apt to come to a wrong conclusion regarding the behaviour of ships among waves.

It is this apparently contradictory behaviour of ships which has given rise to so many theories on the subject. But it was not until the late Mr. Froude brought forward the now generally accepted wave theory that so much light has been thrown upon the subject. To discuss at length the theory of deep sea waves would form a volume in itself, and therefore lies outside the aim of a book such as this. Those wishing to pursue this branch of the subject can find ample information in the volumes of the Institute of Naval Architects, and also in the admirable works mentioned in the preface. We can, however, make a few brief observations, borrowing from the theory mentioned, such principles as may be of assistance to men of practical experience at sea, the class of men which it is the chief aim of this work to assist.

A feather in the air would fall in a straight line to the earth if there were no wind, owing to gravitation. Such fall, however, is always more or less over-ruled by the force of the wind when wind is blowing. Again, an iron plumb ball suspended from a cord, would hang vertically, if undisturbed, owing to the downward attraction of gravitation. On approaching it with a magnet sufficiently close to produce induced magnetism, gravitation is interfered with, and the iron ball seeks to follow the magnet. These instances are related simply to show that under certain circumstances the power of gravitation (such as causes the weight of a ship to act through its centre of gravity in a vertical line) can be over-governed by the introduction of other forces. Thus in waves we have what is termed *centrifugal force*, which, acting along with the gravitation force, gives a resultant force approximately perpendicular to the wave surface. (Before proceeding further, see *note*, p. 153.) Turning to Fig. 93, we can now better understand how it happens that no righting lever was set up, the reason simply being that the lines of action through the centres of buoyancy and gravity coincided, as shown by the arrowed line.

In dealing with a cylinder of no stability, we must not forget that the least external effect of wind or water washing over it might make it revolve; the only resistance offered to this would be the friction of the water on its immersed surface. In the instance we took as an example, we considered it as not affected by any external force, but simply under the influence of the unbroken wave water. Now a modern ship is neither like a raft nor a cylinder, yet it includes in some measure the qualities of both, and may approach either in behaviour.

Ship.—Let us continue our experiment, and, placing an actual ship among waves, watch her behaviour (Fig. 94). If she is very stiff indeed—that is, has great metacentric height, with her still-water rolling period less than half that of the waves she is among she will act very similarly to the raft, which makes two complete rolls on a single wave. Supposing her to be floating in the upright position, immediately the base of the wave reaches her, she will at once seek to keep her masts perpendicular to the wave surface. As the wave passes under her, she will reach, or approximately reach, her greatest angle of inclination on the steepest part of the wave-slope; she will be upright at the summit, and again upright in the trough. She will, therefore, make two complete rolls in passing a complete wave (summit to summit). Her greatest angle will always occur approximately where the wave-slope is steepest. So that the danger in such a ship would lie not in capsizing, for she scarcely ever expends any of her stability, but owing to the rapidity of her movements, to shift the cargo, or strain her structure.



Deck almost parallel to wave-slope, with lines of action through G and B *practically* coincident.

FIG. 94.—BEHAVIOUR OF A SHIP AMONG WAVES.

Synchronism.—But let us suppose that our vessel is tender, possessing a small metacentric height and long rolling period. When the wave reaches her and passes underneath, she will endeavour, as did the other ship, to rear herself perpendicularly to the wave surface. But we observed in our remarks upon rolling in still water that she moves slowly, and so she cannot keep up with the rapid motion of the wave and falls behind.

Thus, by the time the steepest part of the wave is under her, she is still at a considerable distance from that angle. Immediately that point is passed, the less inclination of the wave, as the summit is approached, checks the heeling influence, and at the summit the tendency is to bring her to the upright again. However, here she is yet lagging behind the wave, having still some inclination. When the other slope of the wave is reached she has possibly just reached the upright, and, before she can heel far under its inclining influence to the other side, the trough is reached, where the tendency is to bring her to the upright. We see then, that by her slower movements, she lags behind the wave, and never reaches the angle of the greatest wave-slope, and at the summit and the trough is generally still inclined, not having reached the upright. Taking two such ships upon a single wave, the stiff vessel with the great metacentric height will always reach greater angles of inclination than the tender one with the small metacentric height, simply because, as we have shown, the stiff ship can better follow the angle of the wave; while the tender one of slower motion cannot reach the greatest angle of the wave on the one side of the slope, while, after the wave has passed beneath her, the other slope tends to push her back, and heel her to the opposite side. But, although the passage of the first wave may not have the effect of producing any great angle of inclination, owing to the usually slower movement of the ship in comparison with the speed of the waves, or more properly speaking, *the longer double roll period to the wave period*, it must be clear that a time may come when a ship may reach her greatest angle of inclination when the greatest angle of wave-slope reaches her. The result will then be, that a comparatively sudden additional impulse is given to the heeling of the vessel, and she will take an extraordinary, and what seamen have often called an unaccountable, lurch. Such a condition of waves and ship reaching their greatest angle of inclination at the same moment at regular intervals, is termed *synchronising*, or in other words, *keeping time*, and the effect is to produce considerably greater angles of inclination in the ship than the steepest wave-slope. The worst case is that where the period of a ship's single roll is half that of the wave period, as under such circumstances the impulse is given on each wave, and excessive rolling is naturally set up. This can be further illustrated by a simple pendulum (Fig. 95).

Let us imagine that the pendulum has just swung out to almost its greatest angle of inclination in the direction of the arrow. Suppose it receive a sudden impulse on the side B, it will naturally be checked, and commence its return to the vertical position. But suppose, on the other hand, the impulse had been given on the side A, at the moment the pendulum reaches its greatest angle, when there is neither return nor outward motion. The result is that a slight impulse will considerably increase the extent of its outward movement, and produce a greater angle from the vertical. This is exactly what happens with a vessel whose period of roll synchronizes with the wave period; if a sudden impulse be given near the extremity of her outward motion, a considerable augmenting of the angle of heel will result. The effect is bad enough when the synchronism occurs periodically—that is, with a series of waves—but when it happens on every oscillation, the effect is still more excessive, and the motion experienced by the vessel is rapid and jerky, with the greater probability of producing dangerous results. Stiff vessels with quick periods of about four to six seconds, would be the most likely to develop such behaviour. Vessels of longer or shorter periods may destroy synchronism altogether in most cases.

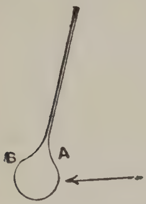


FIG. 95.—INFLUENCE OF EXTERNAL FORCES ON A SWINGING PENDULUM.

Were all sea waves of the same length, period, and height, it would be quite possible to design a warship or a yacht, whose equipped conditions are of an unvarying nature, to give a rolling period in still water which would produce great steadiness among waves.

But sea waves, at different times and places, vary greatly in length, period, height, and character. Atlantic storm waves reach 500 feet and over in length from crest to crest, with periods of 9, 10, or 11 seconds, and heights of 28 feet and over, while in other localities the length may not be more than 200 or 300 feet, with varying periods of 6 to 8 seconds, and height of about 12 feet.

Effect of Loading on Behaviour.—As waves, therefore, vary, according to the locality, the force of the wind, &c., it must be fairly clear that to design either a warship or a yacht to behave always in the same manner among waves is impossible, for although it is not likely that vessels with long rolling periods will be subject to heavy rolling, yet it is most probable that at some time they may fall in with waves which synchronize with their own period, and this inevitably produces heavy rolling. With merchant steamers the difficulty to produce steadiness is more marked than in any other case. In the first place, there is the difficulty, especially in coasting vessels, whose loading has to be rapidly conducted, with possibly part of the cargo arriving just before they sail, of obtaining a certain metacentric height which is known to have produced steadiness on a former occasion; or, if the metacentric height is the same, considerable difference may have taken place in the positions of the weights of the cargo, not vertically, but out on each side from the centre line of the ship.

This brings us to another very important point. While small metacentric height conduces to steadiness, the error must not be fallen into that this mode of procedure can always be carried out. So long as the levers of stability at considerable angles be good, and the range satisfactory, such a method is all very well. But in tender vessels with short levers and short range, as seen by Curves Nos. 11, 12, 6, and 7, Fig. 82, such a method is extremely dangerous, for should synchronism be set up, they may take an excessive roll and capsize altogether, so that it is evident some vessels need more metacentric height than others, in order to ensure safety, even though it produces more lively motions among waves.*

Effect of Transverse Arrangement of Weight on Rolling Motion.—A safe method which can be adopted to assist in producing steadiness in such a case, is to wing out the heavy weights of the cargo, on each side of the vessel, without altering their position vertically. Such an arrangement of cargo will have a steadying effect upon lively transverse motions, and, on the other hand, concentrating the weights in the middle line of the vessel would tend to increase the rapidity of the transverse rolling.†

Alteration in Behaviour during a Voyage.—In ocean ships, whose loading is possibly not so hurried, or at any rate the nature of whose cargo is often understood beforehand, because it is all or nearly all alongside before commencing to load, it is certainly possible to so carry out this method when a knowledge of a ship's stability is understood, as to closely approximate to a particular metacentric height, and moreover to arrange the weights so as to be best fitted for steadiness.

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* It may here be noted that it is utterly impossible to specify a metacentric height adapted to all vessels. For vessels in the Royal Navy, it varies from 1 foot to 12 feet. In steam yachts 2·5 feet is probably an average; in sailing ships 2 to 4 feet is common, and in passenger and cargo steamers it ranges from about 0·5 to about 3 feet. Shipbuilders with their wide experience of the various types of vessels are undoubtedly most capable of suggesting the best metacentric height for any particular condition of loading. The foregoing metacentric heights are *only* for loaded conditions.

† See *Appendix.*

Supposing we have secured a certain metacentric height which has produced great steadiness even in a heavy sea, it is sometimes found that this same vessel in a long, low ground swell of greater period, labours in a most extraordinary manner. Such is not an unknown experience to seamen, and the cause is simply due to the fact that the vessel has now fallen in with waves which synchronize with her own period. An instance bearing on this point was related to the author by a captain. Coming from the Mediterranean with a light cargo, he encountered heavy weather. His ship was naturally tender, and behaved splendidly for some time, but on approaching the Bay of Biscay, a long heavy swell set in, and the ship began to roll so heavily, especially at periodic intervals, that he imagined she would capsize altogether. He immediately set to work and filled one of the water ballast tanks, with the result that the vessel completely altered in her behaviour, and again regained comparative steadiness. The ship had evidently fallen in with waves which synchronized with her own period, and caused the heavy rolling, but by filling a ballast tank the metacentric height was increased and the ship's period altered. Then, there being no longer synchronism, she steadied. Every seaman naturally learns from experience that where heavy rolling is suddenly set up, it can be modified by an alteration in the course or the speed. The reason is not far to seek. If the synchronism is produced by a beam sea, by changing the course more towards the waves, the apparent wave period is decreased, the crests being now passed more rapidly. By taking a course in an oblique direction, away from the direction at right angles to the waves, the wave period is increased, and in any other sea than one direct abeam, an increase in the speed without altering the course will decrease the wave period Thus synchronism can be prevented either by altering the course or speed, and thereby altering the apparent period of the waves, or by altering the period of the ship through shifting weights in the ship.

Synchronism is not always produced by a beam sea, for the sea coming in an oblique direction may cause the vessel's period to synchronize with the wave period, when no such result would have happened with a beam sea, and therefore such large angles of roll could not have been experienced. How to obviate this has just been mentioned—by changing the course, or speed. To attempt to alter the ship's period by filling the water ballast tanks when rolling heavily is by no means a safe experiment, for the moment of the free water dashing from side to side before the tank is filled, may add to the angle of heel, instead of reducing it. We must now be able to see that great stability is not the best condition for a ship, for it will either make her movements exceedingly rapid, following, as in the case of the raft, the wave-slope, or, if not so stiff, tending to produce synchronism, with consequent heavy rolling.

The Metacentric Height.—The *best vessel* is undoubtedly the one with *moderate metacentric height*, *good levers of stability at considerable angles of inclination*, and *good range*. She will probably thus be slow in her period, easy in her movements, and when not subject to synchronism (which she is less likely to be) will be comparatively steady among waves.

To secure steadiness at the cost of small metacentric height, with short levers and range of stability, would only make disaster more probable. This is the very reason why a ship's officer should possess stability curves of his vessel in the various conditions under which she is likely to proceed at sea, from which he will undoubtedly be more able to intelligently manœuvre the condition of his ship in order to produce seaworthiness.

Could we imagine a vessel rolling among waves unresistedly (that is, without being subject to resistance from wind, immersed surface, or keel resistance of any sort), whose own period synchronized with that of the waves, the effect would be that the continued impulses given by the synchronizing waves would eventually capsize her, whatever might be her stability, just as a child's swing pushed synchronically would at last overset. These resistances have the same effect among wave water as when rolling in still water. There is one important point, however, to be observed, and that is, the more rapid the motions of the vessel the more resistance is offered. And thus, upon a vessel whose period synchronizes with the wave period, when she begins to attain large angles of heel and great rapidity of motion, the various resistances grow in proportion until a point may be reached where the effect of these resistances is just sufficient to prevent greater oscillation being attained, and capsizing is also averted. Thus, where synchronism produces great angles of oscillation, it does not follow that the ship will capsize, except in unusual cases where the range of stability is very short.

The great and important value of bilge keels in offering resistance and reducing rolling, has already been shown from Mr. Froude's experiments. These will produce good results upon large ships, but the effect is still more apparent upon small vessels of quick period.

Fore and Aft Motions.—Thus far our remarks have been confined entirely to transverse stability and behaviour relatively to transverse motions at sea, simply because that it is in these directions that danger is most likely to occur. Could we heel our ship in every possible way it would be found that she possessed least stiffness or stability when inclined transversely than in any other direction, and that her transverse metacentric height is the smallest possible. Thus, on heeling in any skew direction, more stability is developed, and most of all when inclined longitudinally (*pitching*). In ordinary types of vessels it is, therefore, only possible for them to capsize transversely, unless it happens that, through damage and the admission of water, the loss of buoyancy at either end is so great as to cause the vessel to go down by head or stern, as the case may be.

This explains why it is only necessary to be provided with curves of transverse stability, and to be thoroughly aware of the vessel's condition in this respect. The greatness of longitudinal metacentric height will be obvious when it is observed that the moment of inertia of the waterline about a transverse axis must be immensely increased beyond that for a longitudinal axis, simply because what was formerly considered as beam in the formula for the transverse metacentre becomes length, and the length becomes beam.

The principles which govern transverse behaviour apply in a similar manner when considering the longitudinal motions of a ship, though here again the design may exercise much influence in the production of objectionable qualities in behaviour. For example, take an ill-designed vessel considerably full on the load waterline aft, but fined away forward with sides almost vertical to the gunwale. Such a vessel will be admirably adapted for diving into the sea and shipping huge volumes of water on her deck, with her stern probably high and dry. However, it must not by any means be inferred that the load waterline forward should be bluff or even identical with the after end, but certainly where any degree of comfort is desired, there should be some reasonable approach to equality. A vessel, very fine under water, may be considerably improved by giving her reasonable *flam* * or flare above the waterline, the additional buoyancy produced by which forms a valuable check upon diving.

But we have also noticed that winging out the weights transversely from the centre line produces slower rolling motion, that concentrating them on the centre line creates greater liveliness, and, moreover, that the latter result is always produced by a large metacentric height, and steadiness by a moderate metacentric height.

Fore and Aft Arrangement of Weights.—With the enormous longitudinal metacentric height—that is to say, length metacentric height, not beam metacentric height—possessed by most vessels, it is impossible to make any visible effect upon the longitudinal motions through this agent, for even were it possible to reduce or increase it by a few feet, the comparative difference would be exceedingly slight. Moreover, such alteration in the position of the centre of gravity might seriously imperil the safety of the vessel transversely. Thus, the only alternative is to influence longitudinal motion by a proper adjustment of the heavy weights of the cargo in a fore and aft direction. If liveliness is required—that is, quick rising motion—they should be stowed nearest to midships; if a slower movement is required they should be spread out longitudinally (that is to say, more fore and aft). But it must not be forgotten that placing heavy weights at the extremities of a vessel has the tendency to excessively strain the structure when subject to the varying support of wave water, and also to some extent when lying at rest in still water.

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* By *flam* is meant exactly the opposite to "tumble home." It is most noticeable at the bow of a ship, where her sides slant outwards, greatly increasing her beam above the load waterline.

Note.—At an earlier stage we have shown that where the water surface is horizontal, the water pressures act in upward vertical lines. This is as true for the smooth surface of the vast ocean as for the water in a bucket. And even when waves have been created, the upward pressures from the ocean depths are in nowise changed. But on coming to the actual waves themselves (which are only surface disturbances extending to a very small depth as compared with the depth of the ocean) we find that the water pressures are now exerted in lines of action approximately perpendicular to the wave surface.

CHAPTER VI. (Section III.)

BALLASTING.

Contents.—Similar Metacentric Heights at Different Draughts—Wind Pressure—Amount and Arrangement of Ballast—Means to Prevent Shifting of Ballast—Water Ballast.

Ballasting.—The number of losses and disasters happening annually, not only to old, but often to fine new ships when in ballast, abundantly proves that something is wrong. This is all the more manifest from the random way in which ballast is often thrown into a ship. One man *considers* 400 tons sufficient, and another, 800 tons for the same ship, and all pitched into the hold. Both cannot be right, since both methods cannot produce similar results. One is either dangerously stiff, conducing to heavy rolling and tending to shift the ballast, or the other is too tender with too small righting moments.

Before ballasting can be intelligently carried out, it is necessary that a few important facts be kept in mind.

1. That *metacentric height alone is no guarantee* for a vessel's stability.

2. That *freeboard alone is no safeguard.*

3. That although a certain metacentric height on one occasion may be very good for a vessel at a particular draught, the same metacentric height would be unsafe at a different draught, and, even *if* it were possible to get the same lengths of righting levers at a certain angle of inclination at light and load draughts, the righting moments in each case would be immensely different.

Similar Metacentric Heights at Different Draughts.—Reference to Curves Nos. 5 and 18 (Fig. 82) will considerably help in illustrating these points. Curve 5 is for a box vessel 100 feet long, 30 feet broad, 10 feet draught, and 5 feet freeboard in the load condition, with a metacentric height of 6·2 feet, the centre of gravity being 6·3 feet from the bottom of the box. Curve 18 is for a box vessel 100 feet long, 30 feet broad, 4 feet draught, and 16 feet freeboard in the light condition, with a metacentric height of 6·2 feet, the centre of gravity being 14·5 feet from the bottom of the box.

Taking metacentric height and freeboard as the only guides, the latter vessel should have by far the greatest stability.

A comparison of the curves contradicts such a conclusion, and shows that the higher the centre of gravity is with a certain metacentric height and freeboard, the smaller will the angle be at which the vertical line through the centre of buoyancy intersects the centre line of the ship below the centre of gravity, hence the increased range of Curve No. 5. Fig. 85 is the stability curve for a sailing barque in the light condition, with 112 tons of ballast aboard. The length is 270 feet, the breadth 41 feet, and the freeboard 17½ feet, with a metacentric height of 2·9 feet and a displacement of 1,390 tons. The maximum lever of stability is 0·69 at 18° of inclination, and the righting moment 1,390 × 0·69 = 959 foot-tons. Moreover, the stability vanishes altogether at the comparatively small angle of 34°.

Wind Pressure.—Both the maximum lever and range are exceedingly small for a heavily-rigged vessel with large sail area, and the effect of a sudden squall of wind with much sail set is easily perceived. In the loaded condition, however, with only 5½ feet freeboard, 4,000 tons displacement, and a much lower centre of gravity with the same metacentric height, this same vessel would have longer levers and much greater moment, as well as greater range of stability.

Amount and Arrangement of Ballast.—Now let us take a practical view of the process of ballasting a ship, and suppose that as master we are told by the naval architect or shipbuilder that a metacentric height of 3 feet in the loaded condition, which gives a displacement of 4,000 tons, will put our ship in an excellently seaworthy condition.

In the light condition, however, by placing 500 tons of ballast in the hold, the same metacentric height is secured with a total displacement of 2,000 tons.

Heeled to an angle of 10°, the righting lever will be—

$$G\,M \times \text{sine of angle} = 3 \times 0{\cdot}1736 = 0{\cdot}52 \text{ foot.}$$

As regards length of lever at this angle of inclination, the vessels are practically identical at both these draughts. The righting moment, however, is lever multiplied by displacement. Thus, at the load draught the righting moment is 0·52 × 4,000 = 2,080 foot-tons; at the light draught the righting moment is 0·52 × 2,000 = 1,040 foot-tons—only one-half the loaded righting moment. It is clear, then, that with equal sail area and equal wind pressure, the vessel in the light condition would heel to a much greater angle than in the load condition; moreover, the effect of a sudden squall of wind will produce about double the angle of inclination which would otherwise be reached in steady heeling. There is always greatest motion at and near the surface of wave water, so that the lighter the vessel, the more on the surface she will float and be subject to the influence of waves and wind. Possessing great stiffness under such conditions, the more excessive will be the rolling. Righting lever alone, then, does not provide righting moment, but lever multiplied by displacement. To get moment without excessive metacentric height, there is no alternative but to considerably immerse the vessel in order to get displacement.

Understanding this, we proceed to put ballast into our vessel. Supposing the ballast to be sand, it would probably be found that if it were all poured into the bottom of the hold, by the time the ship was sufficiently immersed excessive stiffness would be set up.

This method, therefore, cannot be adopted. We know that to reduce metacentric height, low weights must be raised so as to lessen the distance between the metacentre and the centre of gravity. Part of the ballast, therefore, would require to be carried in the 'tween decks. But here, again, a difficulty arises in many cases, where a vessel with good beam, and a depth to require two tiers of beams instead of having a laid deck on the lower tier, this lower tier is made extra strong and the beams are widely spaced, making it impossible to carry ballast higher than the hold. What is to be done? Very often nothing is done, and only one of two conclusions can be arrived at, either the expense of making provision for efficient ballasting is considered too much for some owners whose vessels are amply covered by insurance, or else out of pure ignorance of the mode of ballasting to ensure safety, this subject receives no consideration. One thing which could be done under such circumstances to produce excellent results, would be to build two tanks at the middle of the length of the vessel, one on each side, between the hold beams and upper deck beams, to contain, say, about 50 tons each, or, altogether, 100 tons. Each tank would, therefore, require to be about 30 feet long, 8⅓ feet broad, and 7 feet deep. Especially if the ship were fitted with water ballast tanks in the bottom, the size of these upper tanks could be fixed to a nicety; but in any case, the shipbuilder could supply the information as to the exact amount of hold ballast to be used.

This would reduce the stiffness by raising the centre of gravity, but furthermore, having these weights "winged" out to the ship's sides, would still more conduce to steadiness. The application is, therefore, twofold.

This method entails the expense of the plating, additional beams, and pillars for supporting the tanks. Expense is always objectionable, but there is the choice between possible and probable loss of life through ignorance or carelessness in ballasting, not to mention the ship; and the comparatively small additional cost upon the vessel while building. When loading cargo, and these ballast tanks are not required, the space could conveniently be used for cargo also, if a hatch be made on the deck above them.

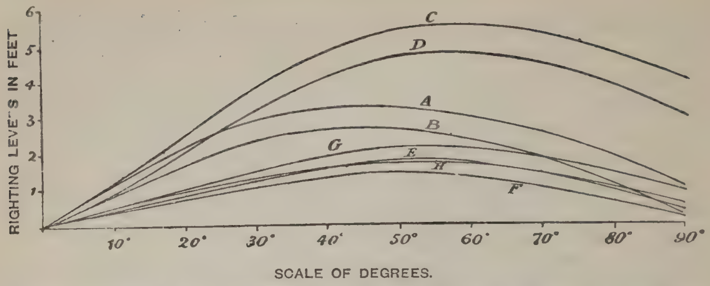
The same idea could be carried out by constructing these ballast spaces of wood battens, instead of iron plating, and using earth or sand ballast. The former method is, however, preferable, and economical, since the water could be run out by means of a cock on the ship's side.

Means to Prevent Shifting of Ballast.—The other great point in ballasting ships is to see that the ballast is secured so as to render the likelihood of disaster from shifting impossible. If it be water ballast confined in a tank, it is all right if the tanks are full, for it must be remembered, as will be pointed out in the remarks upon "water in the interior of a vessel," free water may create a list if the vessel is inclined to be tender. But supposing the ballast to be sand in the hold, great precaution should be taken to make it immovable as far as possible. The value of shifting boards as applied to cargo applies equally to this also, for, after all, ballasting is just a form of loading.

Another method sometimes adopted is to cover the surface of the ballast with boards and shore them down. This is all well enough if the covering and shoring is thoroughly carried out, rendering no possibility of any ballast shifting, or finding its way between the boards or uncovered spaces, for where such is possible the precaution is useless, as the ballast will all the more readily and easily relieve itself from its confinement.

Water Ballast.—Probably most cargo steamers in these days are fitted with some means of carrying water as ballast, simply because, with steam power always at hand, they can most conveniently and economically be filled or emptied as required. Water ballast may be carried in double bottoms, fore and after peaks, or in deep tanks. The last of these methods, when situated near midships, seems the most preferable in producing the best results, for not only does weight so stored form a check upon diving, by making the vessel more lively longitudinally, but it can be better designed to give suitable metacentric height in the light condition. The disadvantage of large fore and after peak tanks is that owing to the fineness of the ends of the vessel they are almost unsupported, and act as hanging weights along a lever, causing severe straining, which is more excessive in the light condition than in any other.

The commonest system in steamers is that of carrying water ballast in double bottoms, which may be partial or continuous

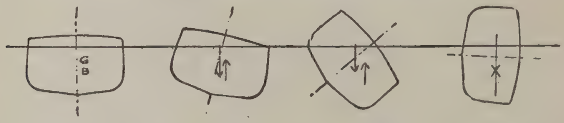


Curves of stability for a steamer. Length, 302 feet; beam, 40 feet 6 inches; depth mld., 24 feet 11 inches. Load displacement, 5,183 tons. Freeboard, loaded condition F = 4 feet 10½ inches.

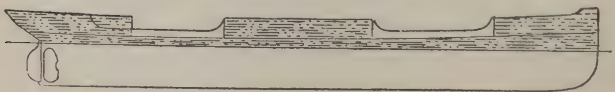
SHIP COMPLETE—STEAM UP.

Conditions.	Bunker Coal, Stores, and Fresh Water.	Water Ballast.	Cargo.	Maximum Stability.		Height of Metacentre above Centre of Gravity.
				Degrees.	Righting Lever.	
					Feet.	Feet.
A	out.	out.	nil.	45	3·31	7·30
B	in.	,,	,,	46	2·68	4·92
C	out.	in.	,,	58	5·58	7·15
D	in.	,,	,,	57	4·77	5·63
E	out.	out.	Homogeneous cargo at 48 cub. ft. per ton.	53	1·85	2·15
F	in.	,,	ditto.	50	1·45	1·99
G	out.	,,	Coal cargo at 45 cub. ft. per ton.	55	2·22	2·62
H	in.	,,	ditto.	52	1·78	2·43

CONDITION F LOADED WITH HOMOGENEOUS CARGO.

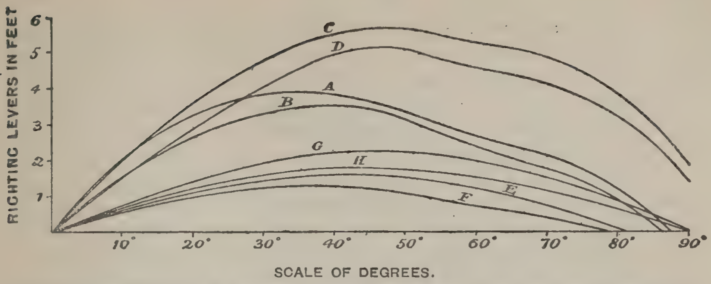


Upright. 13½° Inclination. Deck edge immersed. 50° Inclination. Maximum stability. 93° Inclination. Vanishing point.



Reserve buoyancy as shown by hatched lines for condition F 34·5 per cent. of total buoyancy.

FIG. 96.—CURVES OF STABILITY FOR A STEAMER IN VARIOUS CONDITIONS OF BALLASTING AND LOADING.

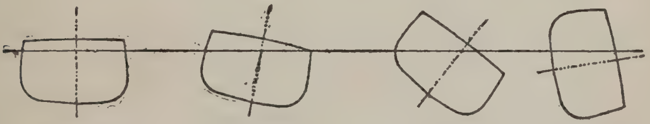


Curves of stability for a steamer. Length, 360 feet; beam, 48 feet; depth mld., 27 feet 3 inches. Load displacement, 8,050 tons. Freeboard, loaded condition F = 5 feet 5 inches.

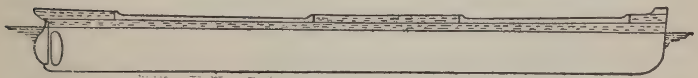
Ship Complete—Steam Up.

Conditions.	Bunker Coal, Stores, and Fresh Water.	Water Ballast.	Cargo.	Maximum Stability. Degrees.	Maximum Stability. Righting Lever.	Height of Metacentre above Centre of Gravity.
					Feet.	Feet.
A	out.	out.	nil.	35	3·96	11·09
B	in.	,,	,,	39½	3·58	8·09
C	out.	in.	,,	45	5·79	10·83
D	in.	,,	,,	46	5·18	8·45
E	out.	out.	Homogeneous cargo at 51 cub. ft. per ton.	39½	1·68	3·16
F	in.	,,	ditto.	37	1·31	3·12
G	out.	,,	Coal cargo at 45 cub. ft. per ton.	43	2·25	4·02
H	in.	,,	ditto.	41	1·82	3·92

Condition F Loaded with Homogeneous Cargo.



Upright. **12° Inclination.** Deck edge immersed. **37° Inclination** Maximum stability. **79° Inclination.** Vanishing point.



Reserve buoyancy as shown by hatched lines for condition F 32·1 per cent. of total buoyancy.

Fig. 97.—Curves of Stability for a Steamer in Various Conditions of Ballasting and Loading.

all fore and aft, and subdivided into several compartments. Here again, regardless of the relation between such an immense weight placed so low down in the ship, and the design of the vessel, these tanks are often filled when the vessel is light or almost light, with the consequent result very often that excessive metacentric height is developed, and the vessel rolls most violently, in some cases even loosening deck fittings, not to mention the extreme discomfort to all on board. A ship's officer, therefore, should thoroughly understand the nature of his vessel's stability with and without the ballast tanks filled.

Figs. 96 and 97, which are curves for actual ships, will serve as references in illustrating the effect of filling ballast tanks, &c.

CHAPTER VI. (SECTION IV.)

LOADING—HOMOGENEOUS CARGOES.

Loading.—All cargo-carrying vessels are not of the same type, proportions, or form; therefore, they cannot all be loaded alike.

Loading does not mean, as some would imagine, the art of throwing into the smallest possible hold space the greatest amount of cargo in the least time. This method might do all very well, probably, for the loading of railway trucks, when the freight is not of a more damageable nature than sand or rubbish, but to adopt such a method in dealing with so sensitive an object as a ship, simply betrays unwonted ignorance. Certain ships lend themselves more than others to the production of objectionable results, but in the majority of vessels built in these days, the person in charge of the loading or ballasting is often more blameworthy for the bad stability and behaviour of his ship at sea than the ship herself. By the term *bad stability* is not only meant too short righting levers or too short range (this might be called deficient stability), but also too much stability, with too long righting arms for small angles of heel, which produces, as observed in Section II., rapid movements, and probably excessive rolling.

Suppose the shipbuilder supplies a captain with a curve of stability for his ship in her loaded condition, with a certain metacentric height. This, while perfectly safe, he also finds produces easy motion and general steadiness at sea. As far as it is possible, he observes and makes notes of the distribution of weights in the hold, as regards their vertical and horizontal position—that is, if the cargo be of a miscellaneous character, and strives to obtain a similar condition on each succeeding voyage, testing at times, when doubtful, the metacentric height in the load condition, before sailing. Now suppose in going to a strange ship he proceeds to adopt exactly the same methods of loading as in the previous one, it is extremely unlikely that similar results would be obtained, for at sea we should probably find her behaviour widely different, and on testing the metacentric height, that she had either far too much, or else too little, or possibly scarcely any at all; the difference in form, proportions, type, or arrangement of permanent weights being accountable for this result.

Thus we see that efficient loading demands much more knowledge, intelligence, and wise discretion than one would at first imagine. Mere rule-of-thumb methods can only produce uncertainty in the majority of cases. A clear understanding must exist as to what is the best condition of seaworthiness.

For all vessels identical in their proportions, in type, and in internal arrangement, it would be an easy matter to fix upon a freeboard and metacentric height such as would ensure the best possible results at sea; but the immense variety of vessels which are continually being built renders this impossible. However, the officer who superintends the loading is relieved from the former of these responsibilities, as this is fixed either according to the rules of the Board of Trade and Registration Societies, or else by the designers, who in some cases prefer to give more freeboard than the rule minimum. Neither can the officer determine the best metacentric height. Here, again, he is dependent upon the builders or naval architect, who by calculation, experiment, and varied experience, are in the best position to specify the metacentric heights under various conditions likely to prove most satisfactory. The responsibility which does rest with the ship's officer is the obtaining of the required metacentric height, without which the freeboard determined by the Board of Trade Rules (a freeboard which is calculated on the necessary conditions being fulfilled to provide the ship in a state of seaworthiness) is by no means of itself a guarantee of safety. As some captains would remind us, it is true that probably with the majority of ships built no such information is provided, much less curves of stability. The reason has been given many times before—namely, that in most cases the ship's officer does not know how to use them if he got them. But it would be unjust to blame him for not understanding a subject about which so little attempt has been made to provide the proper means of obtaining a knowledge of their meaning and use. In the past there has been even a worse feature than this. Probably there are no shipbuilders who have more endeavoured to supply information of this nature than Messrs. William Denny & Brothers, Dumbarton, and yet their experience is the regrettable one, that only in some cases has their information been used. The happy side, however, is that when it has been used, most satisfactory results have been obtained. Shipbuilders have not been much encouraged in the past to go to the additional trouble, except in special cases, of providing information upon stability. It is hoped, however, that with the ever-increasing facilities of education for persons in all occupations, the subject will no longer be relegated to the remote position it has hitherto held, especially among officers of the mercantile marine.

The writer's experience in lecturing has proved that the importance of all the points dealt with in this book is already being more fully comprehended, and that seamen generally are desirous of acquainting themselves with them. Undoubtedly, when such information can be used, shipbuilders as a rule will be only too ready to supply it, if it were for no other reason than the return which ships' officers would be able to make, in giving reliable information to the shipbuilder, which would greatly assist in the development of vessels thoroughly adapted for their special trades.

At this stage a few observations may possibly be made with profit upon the loading of homogeneous cargoes. Although in some respects less complicated than those of a miscellaneous character, nevertheless their varying densities necessitate that their varying effects upon the vessel's stability be understood.

Homogeneous Cargoes.—By a *homogeneous cargo* is meant one all of the same kind, such as a complete cargo of cotton, or coal, or wool, or grain, or timber. All homogeneous cargoes which exactly fill the holds, and bring a vessel down to her load waterline, have the same effect upon the levers of stability, and produce the same amount and range in every case. This is self-evident, since the centre of gravity of every such cargo must occupy the same position, thereby producing in each case identical levers of stability. As the total weight of each such cargo as brings the vessel to the same load waterline must be equal, it follows that the moment of stability, which equals the displacement multiplied by the righting lever, must also be identical; the other conditions, metacentric height and freeboard, which are necessary in the production of similar stability, remaining constant. But supposing that we have a homogeneous cargo of the nature of timber, which necessitates a part of it being placed on deck in order to sufficiently load the vessel to bring her down to the load waterline, then we alter the previous conditions, and the stability is affected.

Having placed a part of the weight constituting the cargo upon the deck, it follows that the centre of gravity will have risen by the distance of the centre of gravity of the deck cargo from the centre of gravity of the ship (when laden with a homogeneous cargo, which simply fills the holds alone and brings her down to the load waterline), multiplied by the weight of deck cargo, and divided by the total displacement. However, although the metacentre always occupies the same position when the vessel is at her load waterline, and the freeboard is constant, yet the reduction in the metacentric height, due to the deck timber raising the centre of gravity, will result in decreased levers of stability, and, consequently, decreased moment and range. But, again, a vessel laden with a light homogeneous cargo, which, like timber, does not put the vessel down to the load waterline when the holds are filled, and is of such a nature that if exposed to the weather would suffer damage, has, consequently, considerably more than the necessary freeboard. The probable result in most cases would be a reduced metacentric height. This would in all likelihood be caused by a lowering of the metacentre and raising of the centre of gravity. It is true that the metacentre ought, according to the formula, to be at a greater height above the centre of buoyancy, owing to the decreased displacement and very slightly reduced moment of inertia of the new waterline; but then the centre of buoyancy has lowered also, owing to the lesser draught, which, altogether, may have produced in the region of the load waterline a lowered metacentre (see *Metacentric Curves*, Fig. 101). This, however, could readily be ascertained from the curve of metacentres.

Coming to the centre of gravity, we should most likely find that the centre of gravity of a homogeneous cargo filling the holds lies below the centre of gravity of the vessel in her light condition; so that the loading of such cargo must produce a centre of gravity for the loaded ship below the centre of gravity in her light condition. When such is the case, it, moreover, follows that the heavier the homogeneous cargo, the greater its effect in producing the lowest centre of gravity and the greatest metacentric height. The lightest homogeneous cargo would therefore produce the highest centre of gravity and the least metacentric height. Thus the conclusion should not be jumped to that the greater freeboard will compensate for the loss of metacentric height and raised centre of gravity, for it might very possibly be found that the whole range of stability had suffered reduction, which would be further influenced by the smaller displacement.

On the other hand, with a homogeneous cargo which puts the vessel down to her load waterline, and yet does not fill the holds, it follows that the centre of gravity must occupy a lower position than when laden with a homogeneous cargo filling the holds. The result in this case is, that the metacentric height being greater and the freeboard unchanged, the lever of stability is lengthened and the moment and range are increased; so that for a vessel engaged in general trade, the value to a shipmaster of a curve indicating her stability laden with a probable light homogeneous cargo with which she is considerably above the load waterline, and another laden with a denser homogeneous cargo, exactly putting her down to the load waterline, must be obvious.

CHAPTER VI. (SECTION V.)

SHIFTING CARGOES.

CONTENTS.—Variations in Stability on a Voyage.

Shifting Cargoes.—Professor Elgar, in a most valuable and instructive paper read before the Institute of Naval Architects, in 1886, upon "Losses at Sea," states that in the three years, 1881, 1882, and 1883, out of 264 British and Colonial vessels registered in the United Kingdom of and above 300 tons gross register, which had been lost at sea under the category of "foundered or missing," one-fourth of these were laden with coal, and one-sixth with grain—very large percentages of the total losses from these causes. It must be remembered, however, that these are two of the largest trades in which British vessels are engaged, but at the same time it is obvious that they are two of the trades in which there is most possibility of cargo shifting. Hence the restrictions laid by the Board of Trade that certain proportions of grain cargoes must be carried in bags, and also that shifting boards be fitted down the centre of the hold, extending at least 6 feet below the deck, and in 'tween decks from deck to deck. Without these restrictions, where both grain and coal are carried entirely loose in the hold, the danger is easily perceivable.

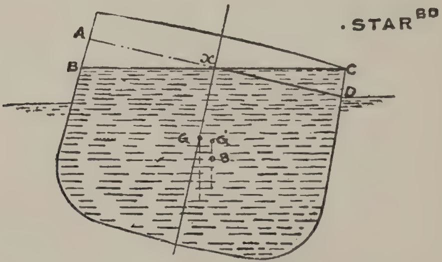


FIG. 98.—VESSEL WITH CARGO SHIFTED.

For example, let Fig. 98 represent a vessel which is so laden. Even if the hold be filled before commencing the voyage, the motion at sea tends to settle the cargo more compactly until there is a space at the top of the hold. Suppose that owing to heavy rolling the cargo shifts as shown, with the result that the vessel takes a heavy list, causing her, in some cases, to be abandoned. The shift of the cargo has affected her stability. Previously, the centre of gravity was at G in the vertical line passing through the centre of the vessel. Now, however, owing to the transference of the wedge of coal, or grain, as the case may be, x A B from the port side, to x C D on the starboard side, the centre of gravity has moved in the same direction. Let the wedge of grain shifted be 40 tons, the distance from the original centre of the wedge to the new centre 20 feet, and the total displacement 3000 tons; then the shift of the centre of gravity in a line parallel to that joining the centres of the wedges will be—

$$\frac{40 \times 20}{3000} = 0{\cdot}26 \text{ foot to starboard side } G'.$$

The levers of stability will now have become reduced for the whole range of the vessel's stability. If she lies at rest at the angle of heel at which she now is, it is evident that she still possesses some stability, though in the present condition the lever of stability is *nil*, it having all been absorbed by the outward movement of the centre of gravity. But the immersion of a new wedge of buoyancy on the starboard side draws out the centre of buoyancy to that side, and produces some stability at greater angles of inclination. Should the cargo shift still further, the whole range of stability may vanish altogether owing to the shortening of the length of the righting levers; or, in other words, if the total heeling moment of the shifted cargo exceeds the greatest righting moment of the vessel, she will capsize. The most dangerous vessels, with a shifted cargo, as their tendency is to be tender, are the older type of small beam to depth. These vessels, fitted with a double bottom for water ballast, show this objectionable feature in a more marked degree, when the tanks are empty, owing to the raised condition of the cargo. It is, therefore, clear that vessels with good beam have the advantage, in the event of such an accident happening, since their form naturally provides them with greater metacentric height and greater resistance to inclination to large angles.

Possibly, the thought may have struck some reader who has observed grain heaped upon a warehouse floor, as to whether a ship laden with loose grain will heel, until the grain surface in the hold is at as large an angle as the surface of the heaped grain, before any shift takes place. If the ship could be heeled slowly and steadily, no shift of cargo would occur before the surface of the grain has reached as great an angle as it is possible to heap it upon a floor, as in Fig. 99, *a b* and *a b* being at the same angle of inclination.

If this answer were correct in all cases, possibly a little less uneasiness might be felt as regards shifting cargo, for the late Professor Jenkins, in a paper read before the Institute of Naval Architects, on this subject, gives the greatest angles to which it is possible to heap a free surface of wheat (or, as it is termed, the *angle of repose*) at 23¼°, which is considerably less than that of most grain, and as grain-laden vessels are generally inclined to be tender, and, therefore, usually roll less, the angles of repose for grain are greater than many such vessels would roll through.

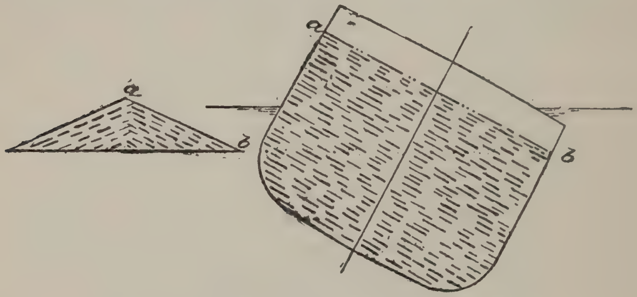


Fig. 99.—Angle of Repose for Grain.

But this is not the case, for the effect of rolling, pitching, and blows from the sea is to reduce the angle of repose considerably. Moreover, movement of cargo will take place all the sooner, the greater the distance its surface is situated from the centre about which the ship rolls, hence, cargo in the 'tween decks will shift sooner than cargo in the hold.

When it is known that shifting boards extending down the middle line of a ship reduce the heeling moment of shifted cargo to about one-fourth of what it would be without them, their value will then be better understood.

Variations in Stability on a Voyage.—Steamers are especially liable to considerable change in their stability and behaviour at sea between the time of leaving one port and arriving at another.

This is chiefly due to the consumption of bunker coal.

Take an ordinary cargo vessel which on a six days' voyage from one port to another consumes, say, 100 tons of coal. Naturally the displacement will be reduced by 100 tons, and by referring to the "tons per inch" curve it may be ascertained how many inches the draught has decreased, evidently giving greater freeboard in the first place.

The effect upon the metacentric stability will depend chiefly upon the position of the centre of gravity of the bunker coal. In the case where the bunkers are situated on each side of the boilers, and in a cross bunker extending from the top of the floors to the first deck when there are two or more decks, the centre of gravity of the bunker coal will generally lie below the centre of gravity of the ship, making the ship stiffer. When the coal is consumed the vessel will become more tender, and usually steadier when among waves, due to the reduced metacentric height.

But as is more common in these days among tramp steamers of good beam, where, in order to get the greatest reduction on the tonnage by obtaining the largest possible propelling space (see *Tonnage*), the practice of almost dispensing with lower side and cross bunkers is adopted, and the coal is carried in the 'tween decks at the sides of the engine and boiler casings. Frequently an additional 30 or 40 tons are placed on the bridge deck, and kept there by means of temporary boards secured to the rails, or by closed-iron bulwarks. In such cases the centre of gravity of the coal is much above the centre of gravity of the ship, producing reduced metacentric height and greater steadiness. But on the consumption of this coal, the top weight being removed, the centre of gravity lowers, the ship becomes stiffer, and is found to roll more than previously.

After lecturing on this subject on a certain occasion recently, a captain who was one of the audience related the following uncommon incident in his own experience, an incident which he had never been able to understand:—

Coming up the Irish Sea to Liverpool almost at the end of a homeward voyage, laden both in holds and on deck with esparto grass, the vessel began to indulge in most peculiar movements. There was not much sea, and previous to this time the vessel had been exceedingly steady; but now she commenced to take a slight list, and to move occasionally from side to side with a jerk, and not with a rolling motion. She would then lie still after one of these movements, except for the rising and falling of the waves, until after another interval another wave lifted her up, and she jerked to the other side, there again lying for a time, the motion being repeated at intervals. As this captain now explained, the vessel having a light homogeneous cargo, had been very tender, and all the more so with the deck cargo. The bunkers being situated low down in the vessel, the consumption of coal on the homeward voyage must undoubtedly have still further reduced the metacentric height. Moreover, during the latter part of the voyage the deck cargo became soaked with rain, which made it heavier and more effective in raising the centre of gravity, until at last the centre of gravity actually coincided with or rose above the metacentre. In the latter case an upsetting lever having arisen, the vessel heeled, until by the immersion of a new wedge of buoyancy this heeling force was absorbed. The vessel was now practically in a similar condition to the homogeneous cylinder we considered in Fig. 93, except that on being still more inclined, the immersion of another new wedge of buoyancy caused the righting levers of stability to grow again, which resisted further inclination.

Thus the cause of the vessel jerking from side to side was not due to the effect of any righting moment, but simply to the heaving motion of the sea pushing her occasionally to the upright, and then losing her balance, being in a state of neutral equilibrium, she dropped over to the other side.

Any vertical movement of weights, or increase or decrease of weights already on board, will in some degree influence the stability, which, as has been shown, will affect her motion among the waves.

Emptying or filling water ballast tanks may have a similar effect.

CHAPTER VI. (SECTION VI.)

EFFECT OF ADMISSION OF WATER INTO THE INTERIOR OF A SHIP.

CONTENTS.—Admission through a hole in the Skin into a Large Hold—Curves, showing Variation in Height of Metacentre with Increase of Draught—Buoyancy afforded by Cargo in Damaged Compartment—Longitudinal Bulkheads—Entry of Water into Damaged Compartment beneath a Watertight Flat—Entry of Water into Damaged Compartment above a Watertight Flat—Value of Water Ports—Water on Deck—Entrance of Water through a Deck Opening—Entry of Water into an End Compartment—Height of Bulkheads—Waterlogged Vessels.

Effect of the Admission of Water into the Interior of a Ship.—1. *Through a hole in the Skin below the Load Water-line :—*

Let Fig. 100 be a box-shaped vessel 100 feet long, 20 feet broad, 10 feet draught, and 5 feet freeboard. For the sake of example, let there be a watertight compartment, one-fourth of the length of the vessel—viz., 25 feet—situated at the middle of the length, and bounded at each end by a watertight bulkhead, as shown. We will suppose this compartment to be damaged by collision, and the sea to enter by the hole indicated.

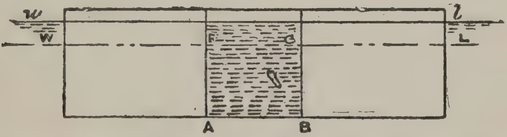


FIG. 100.—EFFECT OF ENTRY OF WATER INTO A CENTRAL WATERTIGHT COMPARTMENT.

After the damage the draught of water will have increased from W L to *w l*, for, as was pointed out in the Chapter on *Buoyancy*, the buoyancy of the compartment into which the water has entered having been lost, in order to support the weight of the vessel which remains unchanged, the reserve buoyancy in the other intact compartments has had to be drawn upon, hence the increase of draught. But let us see what effect this has had upon the metacentric height. The rule for metacentre above centre of buoyancy is—

$$\frac{\text{Moment of inertia of waterline}}{\text{Displacement in cubic feet}}$$

Now, in taking the moment of inertia of the new waterline of this vessel, the compartment into which the sea has entered is entirely ignored, and treated as though it were no part of the vessel, since it affords no buoyancy. The moment of inertia of the new waterline *w l*, less the part F G, divided by the displacement, equals the metacentre above the centre of buoyancy. It will be pretty evident that the moment of inertia will have decreased considerably owing to the loss of a part of the waterline area, which must result in bringing the metacentre nearer to the centre of buoyancy. The position of the centre of gravity of the ship remaining unchanged, it would appear to follow, at first sight, that in every such case the metacentric height is reduced. But let not the important fact be overlooked that the centre of buoyancy must have risen with the increase of draught. Possibly a simple calculation may more effectively throw further light upon this. Referring to the box vessel before the accident occurred :—

The displacement was $100 \times 20 \times 10 = 20{,}000$ cubic feet.

$$\text{The moment of inertia of the waterline} = \frac{100 \times 20^3}{12} = 66666.$$

$$\text{The metacentre above centre of buoyancy} = \frac{66666}{20000} = 3{\cdot}3 \text{ feet.}$$

The metacentre above the bottom of the box is $5 + 3{\cdot}3 = 8{\cdot}3$ feet.

Let the centre of gravity be, say, 6·3 feet from the bottom of the box, then the metacentric height in the undamaged condition is $8{\cdot}3 - 6{\cdot}3 = 2$ feet.

For curve of stability (see Fig. 82, Curve No. 3).

After the collision, the draught is found to have increased 3·3 feet ; this is arrived at by dividing the volume of the lost buoyancy F G B A (Fig. 100) by the total area of the waterline, less the part F G.

The centre of buoyancy is therefore—

$$\frac{10 + 3{\cdot}3}{2} = 6{\cdot}6 \text{ feet from the bottom of the box.}$$

The displacement remains unaltered at 20,000 cubic feet.

$$\text{The moment of inertia of the waterline} = \frac{75 \times 20^3}{12} = 50000.$$

$$\text{The metacentre above the centre of buoyancy} = \frac{50000}{20000} = 2{\cdot}5 \text{ feet,}$$

which is lower than formerly.

The metacentre above the bottom of the box $= 6{\cdot}6 + 2{\cdot}5 = 9{\cdot}1$ feet, which is higher than formerly.

Then the metacentric height after the collision is $9{\cdot}1 - 6{\cdot}3 = 2{\cdot}8$ feet, which is greater than formerly.

Thus we see that the vessel has actually a greater metacentric height after the accident with the compartment flooded than she had originally in her intact condition. At first one is almost tempted to jump to the conclusion that this could scarcely be the result, for if such be the case, why the loss of so many vessels subdivided into numerous watertight compartments? and we may point to the battleship "Victoria," and the more recent disaster to the "Elbe." To understand this, it is necessary to carefully trace the effect of the chief influencing agents, upon which the initial or metacentric stability depends, from the moment the collision happens to its climax. Be it observed, however, that while the metacentric stability is less for this box ship in the undamaged condition, yet the stability for greater angles of inclination is unquestionably superior. This is accounted for by the greater freeboard. Moreover, all ships cannot be classed as boxes, and the difference in form and the fining away of the waterlines (or beams) towards the ends, has a very marked effect upon the height of the metacentre, owing to the great reduction in the moment of inertia of the waterlines.

Variation in Height of Transverse Metacentre owing to Increase of Draught.—It is generally found in merchant vessels that for light draughts the metacentre is highest, owing to the small displacement in comparison with the moment of inertia of the waterlines, but as the draughts increase the immense bulk of the vessel grows more rapidly in proportion than does the moment of inertia. The result often is that the metacentre falls, until, when approaching the load waterline, the lowering effect of the increasing displacement is less than the raising effect of the centre of buoyancy, owing to the increasing draught, and the metacentre rises again.* This leads us to the important fact that dangerous as the shipping of heavy seas may be into large wells upon the decks of many vessels, yet in some cases, owing to the increased draught from such sudden deck weight the metacentre rises, and this greatly tends to avert what might often be a serious condition.

In Fig. 101 several examples are given for different types of actual ships, showing the effect of increased draught upon the height of the metacentre, as shown by the curves. The table on the same page gives the particulars for each vessel.

It will also be noticed that a collision happening in way of a moderately large compartment at or near amidships, the loss of this most effective moment of inertia of waterline (the beam being greatest here), greatly modifies the results obtained from vessels of box form, and makes impossible such increase in metatentric height as is obtained from our box vessel with its central compartment flooded (Fig. 100). In the box vessel in our illus-

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* Flare out on the load waterline at the ends of a vessel increases the moment of inertia and tends to produce the same result.

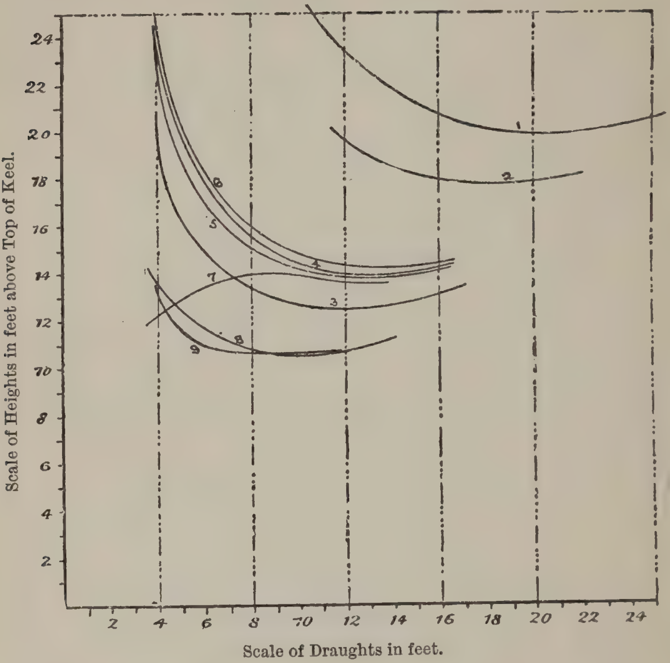

FIG. 101.—CURVES OF METACENTRES, SHOWING UPWARD TENDENCY IN REGION OF LOAD DRAUGHT.

No. of Vessel.	Length.	Breadth.	Depth Moulded.	Load Draught.	Description.
	Feet.	Ft. in.	Ft. in.	Ft. in.	
1	320	45 3	28 0	22 0	Full sailing ship.
2	270	41 0	26 3	21 0	Full sailing ship.
3	206	28 6	15 10	14 0	Fine steamer.
4	231	32 0	17 4	15 0	Moderately full steamer.
5	215	31 10	16 3	15 0	Moderately full steamer.
6	245	33 0	17 3	15 9	Moderately full steamer.
7	190	27 6	18 0	12 0	Steam yacht.
8	162	22 0	14 4	11 6	Steam yacht.
9	154	22 0	13 6	9 0	Steam yacht.

tration the draught was 10 feet, and the freeboard 5 feet, and if these figures be for loaded conditions, the amount of freeboard, and, consequently, reserve buoyancy, is exceptionally great.

Had there been anything less than 3·3 feet freeboard she would have foundered, the weight of the vessel more than swamping the total remaining buoyancy after the collision. But probably neither the "Victoria" nor the "Elbe" sank from this cause, for before the reserve buoyancy had been exhausted they capsized.

Let Fig. 102 represent the section of a vessel in way of a damaged compartment, the buoyancy of which compartment is less than the remaining reserve buoyancy, thus proving that there is, at any rate, capacity to float after the inflow of water has ceased.

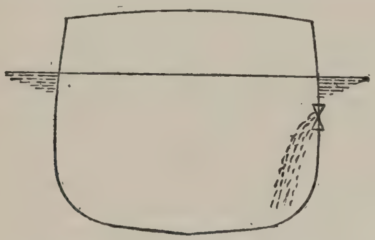

Fig. 102.—Influx of Water into Damaged Compartment.

Water flows in through the hole X, and if the hole be large, as it usually is under such circumstances, the immense weight of water which rushes in *on the one side*, together with the natural tendency of water to find the lowest possible position, has the effect, for the time being, of drawing out the centre of gravity of the vessel in the same direction—that is, towards the side of the ship where the hole is, and the vessel takes a list.

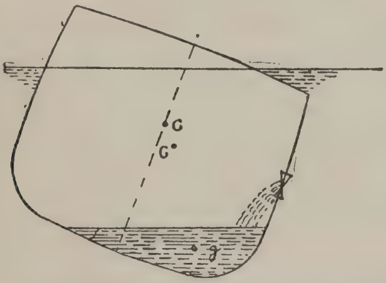

Fig. 103.—List Caused by Influx of Water.

The water already in the compartment naturally seeks a horizontal surface, as shown in Fig. 103, with its centre of gravity *g* well over to the heeling side, adding to the inclination.

The continuous pouring in of water, accompanied by increasing list, and the added effect of the water which has already entered, combine to increase the heeling process, and thus eventually, in many cases, when the heeling moment from these causes exceeds the greatest righting moment indicated by the vessel's curve of stability, she capsizes. If the vessel be very stiff in the upright condition, in some cases she will resist the heeling caused by the water pouring in, and she will do this all the more easily after a moderate quantity has entered, as this has the effect of lowering the centre of gravity and adding to the stiffness and resistance to further inclination, and eventually, when the reserve buoyancy has been drawn upon for the loss of the buoyancy of the damaged compartment, she may remain at rest in a condition of stable equilibrium.

Buoyancy afforded by Cargo.—It should be noted that immediately after the collision the weight of water pouring in acts exactly as deadweight, lowering the centre of gravity and increasing the draught. But after the compartment is filled to the level of the water outside the ship—and the water inside the ship continues to be freely in contact with the water outside—the entered water is no longer considered as weight, any more than the water outside the ship is weight, since this space has ceased to represent floating power (excepting the cubic capacity of the cargo inside, if there be any, for displacement is always actual buoyancy), and the entered water is, therefore, dismissed as being no part of the vessel; in fact, the vessel is now identical with Fig. 104.

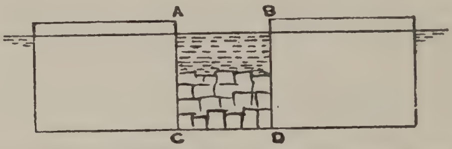

FIG. 104.—EFFECT OF WATER IN A COMPARTMENT WITH CARGO.

Here we have two intact end compartments. The middle space, A B D C, has only, say, a bottom upon which rests weights representing cargo. There are no sides to this compartment, but simply the means for holding the structure together. In this example we have an exact illustration of the vessel we have been considering. The whole is being supported by the buoyancy of two intact end compartments, together with the volume of the cargo, which also affords its cubic capacity of buoyancy, though beneath the water level. The centre of gravity is the actual centre of the weight of the ship and her cargo, the water in the space over the cargo neither affecting its position nor adding to the weight.

Thus we see that in an actual ship the entry of water may at first affect the centre of gravity, yet after the inflow has ceased, having reached the water level outside, the centre of gravity is again in its original position. If the vessel is tender in the upright condition, she will heel all the more easily under the effect of water so entering.

Longitudinal Bulkheads.—Should the vessel possess a longitudinal watertight bulkhead down the middle of her length, instead of this providing a means of safety, as is sometimes supposed in such an accident, it simply adds to the effect of the water in heeling the ship, and by robbing the ship of buoyancy upon one side only tends all the more to the production of the often disastrous result. In cases of war and passenger vessels, where a system of exceedingly numerous watertight compartments is adopted, damage to one or more of these compartments may not produce very serious results, though possibly causing a list owing to loss of buoyancy, perhaps, on one side only. Being devoid of this floating support, the centre of buoyancy can no longer lie in the middle line of the vessel, but in the centre of the actual remaining immersed buoyancy, though, if the vessel remain at rest, it follows that the centre of gravity and the centre of buoyancy are in the same vertical line.

It should be observed, however, that the loss of many vessels, thoroughly subdivided into watertight compartments, is often due to the fact that they have so many watertight but unclosed doors. Collisions generally happen at unexpected moments, and often in fine weather, when many of these doors are open, with the result that when the collision occurs, they cannot be reached, or are entirely forgotten, and hence the result.

Entry of Water into a Compartment beneath a Watertight Flat.—Instead of the whole middle compartment being open to the inroad of the sea after damage to the skin, let us

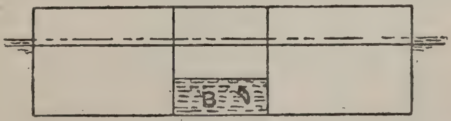

Fig. 105.—Effect of Entry into a Watertight Compartment below Partial Deck.

suppose that a watertight flat or partial deck situated at one-half the depth of the original draught (5 feet) be fitted as in Fig. 105, and the sea to enter through a hole into the lower compartment. Let us now observe the effect upon the metacentric height. The waterline being entirely intact, the moment of inertia must be reckoned upon the whole area. The metacentre is 3·3 feet above the centre of buoyancy as for the vessel undamaged.

The volume of the lost buoyancy of the compartment B, divided by the area of the effective waterline gives the increase of draught—

$$\frac{2500}{2000} = 1{\cdot}25 \text{ feet} = \text{increase of draught.}$$

The centre of buoyancy of the intact end compartments only, from the bottom, is—

$$\frac{10 + 1{\cdot}25}{2} = 5{\cdot}62 \text{ feet.}$$

The effect of the buoyancy above the watertight flat is to raise the centre of buoyancy for the whole vessel to 6·01 feet above the bottom.

The metacentre above the centre of buoyancy is 3·33 feet.

The metacentre above the bottom of compartment is 6·01 + 3·33 = 9·34 feet.

The centre of gravity above bottom of compartment is 6·3 feet.

Therefore, the metacentric height is 9·34 − 6·3 = 3 feet, which is greater than for the vessel in the original intact condition, and also, as in the foregoing example, where the whole compartment between the watertight bulkheads is lost buoyancy. Moreover, with intact waterline and upper buoyancy, a little study of the wedges of immersion and emersion will abundantly prove that in every respect its stability is improved.

Entry of Water into an Upper Compartment.—But again, supposing the upper compartment to have been damaged, as in Fig. 106, we shall see that the effect is greatly different. First of all, the moment of inertia is reduced owing to the loss of the space F G. The moment of inertia of the waterline, and, consequently, the height of the metacentre above the centre of buoyancy, are now the same as in Fig. 100, the latter being 2·5 feet.

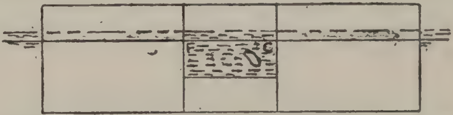

Fig. 106.—Effect of Entry of Water into an Upper Compartment.

The loss of buoyancy below the waterline is the same as in the last case, but the increase of draught is more, owing to the effective area of the waterline being reduced by the space F G.

$$\text{The increase of draught is } \frac{2500}{1500} = 1{\cdot}66 \text{ feet.}$$

The centre of buoyancy of the intact end compartments only above bottom of box is—

$$\frac{10 + 1{\cdot}66}{2} = 5{\cdot}83 \text{ feet.}$$

The effect of the buoyancy below the watertight flat is to lower the centre of buoyancy for the whole vessel to 5·42 feet above the bottom.

The metacentre above centre of buoyancy is 2·5 feet.

The metacentre above the bottom of the box is $5{\cdot}42 + 2{\cdot}5 = 7{\cdot}92$ feet.

The centre of gravity above the bottom of the box is 6·3 feet.

Therefore, the metacentric height is $7{\cdot}92 - 6{\cdot}3 = 1{\cdot}6$ feet.

It will be very clear that this case is vastly different from the previous one, for not only are the metacentric height and freeboard less, but the total loss of the upper buoyancy above the watertight flat will greatly reduce the effect of the immersed wedges in producing the levers of stability.

Value of Water Ports.—*Effect of water on deck, and necessity of ample freeing ports.*

In well deck vessels of the raised quarterdeck type, and also those with poop, bridge, and forecastle, special care should be taken that ample means be provided for speedily ridding the space between the forecastle and the bridge, and also between the bridge and the poop, of water accumulated through the shipping of heavy seas. In addition to the discomfort and the strain to the structure from such sudden and heavy deck weights, the vessel's stability may, under certain circumstances, be seriously affected, and if the water be not rapidly cleared, may prove a source of real danger. This is easily perceived when we consider the enormous weight which from time to time is poured on the deck during heavy weather, and this weight being considerably above the centre of gravity of the ship, the effect is to raise the centre of gravity *possibly* to a height above the metacentre.

Suppose a vessel of 2,000 tons load displacement has a well between the bridge and the forecastle 60 feet long, 34 feet broad, and with bulwarks 4 feet high. This space would hold $\frac{60 \times 34 \times 4}{35} = 233$ tons. That shipped seas would often entirely fill this space would be unlikely; but suppose, for example, that it be three-fourths filled, the water shipped would weigh 175 tons. The centre of gravity of the weight being, say, 10 feet above the centre of gravity of the vessel, the effect is to raise the position of the latter $\frac{175 \times 10}{2000 + 175} = 0{\cdot}8$ foot.

Supposing the vessel's metacentric height to be ·6 foot—not at all uncommon in many cases of loading—then the centre of gravity is now approximately 0·2 foot above the metacentre, supposing no rise to have occurred in the height of the latter. In this condition it follows that the vessel is unable to remain upright, apart from the influence of the waves, and commences to heel, the water all rushing towards the inclining side. The original metacentric height is only regained by the water pouring over the bulwarks and through the freeing ports, which latter should therefore be amply sufficient to speedily clear the deck.

The danger will be all the more obvious in vessels possessing deep wells, the bulwarks of which extend to the height of the bridge and forecastle, usually about 7 feet. It will be evident that such a vessel, unless capable of speedily relieving herself of the water through the water ports, will heel to a greater angle before getting rid of much of it over the bulwarks. The concentration of this water to one side, when inclined, and the possible synchronism of a wave, may lead to disastrous results. Certainly, as some reader may suggest, this is an extreme case, but the fact that so many vessels are, in ignorance, sent to sea unseaworthy, and so many are recorded annually as "foundered," and "unheard of," demands attention, and furthermore proves that extreme cases are not so uncommon as is often imagined.

Entrance of Water through a Deck Opening.—*Effect upon Stability owing to the Admission of Water into the Interior, either through a Damaged Deck or Deck Opening.*—This case differs from the previous ones in the fact, that the skin being perfectly intact, there is no free communication between the water inside and outside of the vessel. There is, therefore, no loss of buoyancy, the entered water acting directly as deadweight, and thereby increasing the draught. If this operation were to continue until the total weight of displacement exceeded the total buoyancy, the vessel would sink. Should the entered water be only moderate in quantity, through, perhaps, leakage in the deck during heavy weather, let us briefly observe the possible effect upon the stability.

If the vessel be very flat on the bottom, the effect, as Professor Elgar very aptly points out in the paper previously referred to, will be similar to that of water poured slowly into a box. Water naturally seeks the lowest position, and this will only be accomplished by the vessel inclining, and lowering one of the bottom corners. At first, only a slight list is perceived, but as the amount of water in the interior increases, the list continues to increase until the centre of gravity of the water finds a position in the vertical line through the centre of buoyancy, after which, the water, which was previously the inclining element, now resists further inclination.

Let Fig. 107 be a vessel which has gone through these stages of inclination. If she then remains at rest it proves at once that the vertical lines through the centre of gravity and the centre of buoyancy coincide, the centre of gravity having moved from G to G′, owing to the effect of the shifted water. If a vessel has more righting moment of stability (righting lever × displacement) at any angle of heel than the inclining moment at corresponding angles (weight of water × perpendicular distance between $g\ g'$),* then the vessel will return to the upright. The vessel in our example (Fig. 107) was more tender, for as the water entered slowly she inclined gradually, thus showing that the heeling moment of the water was exactly absorbing the righting moment of the vessel, and thus leaving her, at each successive angle of inclination, in a state of neutral equilibrium. She could not heel all at once to her greatest angle of inclination, simply because the heeling moment was not sufficient to absorb the righting moment of the vessel until more water had entered.

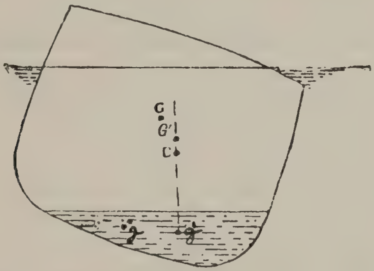

FIG. 107.—EFFECT OF WATER COLLECTED IN THE BOTTOM OF A VESSEL.

In Fig. 107 let the weight of water in the hold be 50 tons, and the displacement of the vessel in this condition 1,000 tons. In the upright condition the centre of gravity of the water was at g, but after the inclination it is found to have travelled 6 feet, to g'. The effect is to draw out the centre of gravity of the vessel in the direction of the moved water, which distance is $\frac{50 \times 6}{1,000} = 0{\cdot}3$ foot.

---

* g is centre of gravity of water in upright condition, and g' in inclined condition.

Owing to the shift of the centre of gravity a distance of 0·3 foot, to, say, starboard side, the effect is the same as deducting 0·3 foot from the lever of stability with no water in; and thus where the curve of stability shows 0·3 foot of lever, there would in reality be no lever at all, and at this angle the vessel would lie at rest if undisturbed. If the vessel were forcibly inclined further, she would probably return to this position again immediately on the inclining force being removed, proving that beyond this angle her righting moment exceeded the heeling moment of the water.

If the vessel were now forcibly heeled to the port side and again left undisturbed, she would lie at the same angle of inclination as on the starboard side. Should it happen that the greatest righting lever of the vessel at any angle of inclination did not exceed 0·3 foot, she would undoubtedly capsize.

The more rise there is on the bottom of the vessel, the less danger or likelihood is there of water thus taking a permanent shift, since this form of bottom makes the upright the lowest position that entered water can find. In such a case, the entry of a moderate quantity of water is to lower the centre of gravity and give more metacentric height. But at the same time it will be remembered that great metacentric height conduces to heavy rolling, which motion will be transmitted to the water inside, tending, it is possible, to incline the vessel further than she otherwise would. These latter remarks apply also to free water in water ballast tanks, which, in addition, sometimes does considerable damage by its force.

Entry of Water into an End Compartment.—Thus far it will be observed that only the effect upon transverse motion has been dealt with, and that in the foregoing examples the water is supposed to have entered into a compartment in the middle of the length, and thus to have increased the draught uniformly all fore and aft. However, where a compartment is damaged at or near the ends of the vessel, not only may there be tendency to transverse inclination, but longitudinal also.

Thus in Fig. 108 let G be the centre of gravity and B the centre of buoyancy in the intact condition. Should the vessel be now damaged through collision in the fore compartment, C D, and the sea find free entrance, then the buoyancy of this compartment being lost, the draught must increase, and the centre of buoyancy will endeavour to shift into the centre of the remaining buoyancy, B′. But the centre of gravity and the centre of buoyancy being no longer in the same vertical line, a condition of unrest is the result, there being a lever set up between the vertical lines through these two forces. The vessel will, therefore, heel longitudinally and go down by the head, and will not come to rest till the centre of buoyancy is again in the same vertical line with the centre of gravity. The larger the compartment damaged, and the greater its distance from the original centre of buoyancy, the greater will be the change of draught and trim, with, possibly, disastrous results, for it will be seen that immediately the stem has gone under water, when such calamities happen there are possibly several deck openings or companions uncovered, and the sea finding inroad through these, adds to the effect by making its way to that end of the vessel which is inclined.

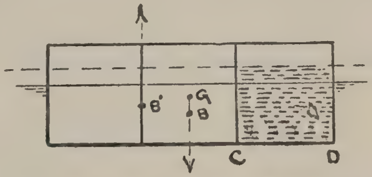

Fig. 108.—Effect of Entry of Water in Fore Compartment.

Height of Bulkheads.—It will now be better understood why a watertight bulkhead should be placed at a short distance from each end of all vessels, for these localities are most likely to suffer in case of collision, and, moreover, being at so great a distance from the centre of buoyancy, their loss of floating moment is great. Hence the necessity of carrying all bulkheads, and especially watertight ones, as high as possible, in order to prevent water finding its way over the tops of them into the next compartments.

Waterlogged Vessels.—It is not an unfrequent sight during bad weather in the Baltic, where such a large percentage of the export trade is in timber, to see an old wooden ship, laden with timber in both holds and on deck in a waterlogged condition. There she lies with a heavy list, rising and falling with each successive wave, with scarcely ever a movement of her own (Fig. 109).

She has sprung a leak, and water has found its way into her hold and risen to the level of the sea outside. There being now free communication between the sea and the water inside, the whole of the interior space *unoccupied* by timber—every crevice and corner—is lost buoyancy. The result is the draught increases, but not the displacement, until a volume of water has been displaced by the timber and the framework of the vessel equivalent to the original volume of displacement. Undoubtedly the centre of buoyancy has risen. It will now be situated in the new centre of displacement, which no longer constitutes the portion of the ship which is immersed and within the skin, but the centre of the immersed portion of ship and timber unoccupied by water. The centre of gravity has remained stationary. If the metacentre had remained in the same position relatively to the centre of buoyancy, the ship, since the centre of buoyancy has risen, would actually be stiffer than before the leak took place, when she was probably very tender. The permanent list proves that such is not the case, and we can rightly come to the conclusion that a considerable reduction has occurred in the height of the metacentre.

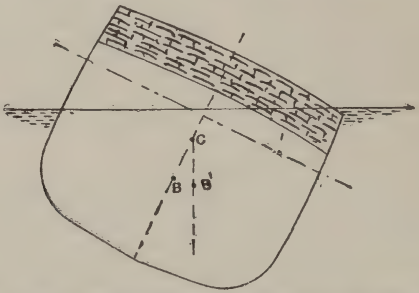

Fig. 109.—Waterlogged Timber-laden Vessel.

It has not been caused by the displacement, for that is unchanged. It can only lie in the moment of inertia of the new waterline, which is no longer for the whole area of the waterline at which the vessel floats, but simply for the sectional area of *actual* timber (both cargo and ship), at that waterline. It will now be found that the moment of inertia is considerably less, and when divided by the displacement, gives a position for the metacentre below the centre of gravity. The vessel is, therefore, unstable, and heels over, and possibly in some cases, were it not for the volume of wood on deck, she might capsize altogether. But she is prevented from this by the effect of the immersed wedge of timber, which acts as freeboard, giving buoyancy exactly where it is most needed to keep the vessel afloat.

The effect has been to draw out the centre of buoyancy from the original position B, to B′, Fig. 109, until the vertical line through the new centre of buoyancy coincides with the vertical line through the centre of gravity. The vessel now rests in a state of neutral equilibrium, having no righting lever of stability at this angle of inclination.

CHAPTER VI. (SECTION VII.)

SAILING, SAIL AREA, &c.

Sail Area.—In briefly considering the subject of the capability of a vessel for carrying sail, our study of "Moments," Chapter II., again proves of great assistance; moreover, we shall also discover that sail area is inseparably connected with stability.

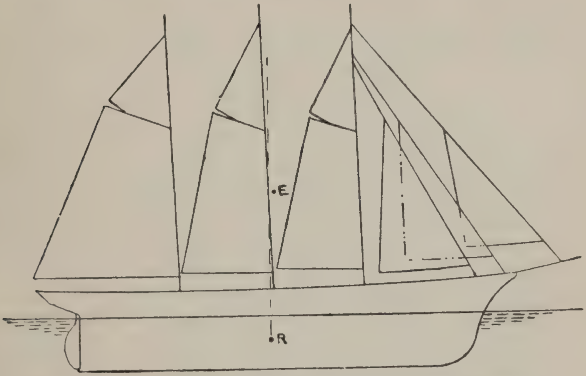

FIG. 110.—THREE-MASTED SCHOONER-RIGGED VESSEL.

Fig. 110 is an outline sketch of a three-masted schooner-rigged vessel, which will serve as an example for reference.

Sails might aptly be compared to a number of weights ranged miscellaneously along a lever; the lever would, therefore, be an imaginary line passing from the region of the hull to beyond the topmast sails. Before we could possibly calculate the moment of pressures about a point at the end of a lever, we should have to determine the position of the end of the lever from which the moments are calculated. Exactly the same thing takes place in dealing with sails; we must determine the end of the imaginary lever. This point is called the *centre of lateral resistance*, and is the centre of the resistance of the water to lateral or broadside motion. Such movement would, therefore, be square, or at right angles to the forward motion of the vessel, and is usually termed *leeway.* The centre of lateral resistance varies in position, but it is approximately and sufficiently correct for all practical purposes at the centre of the immersed longitudinal section, passing through the middle line of the ship. In comparing pressures on sails to weights on a lever, it is not meant that the actual sail acts as a weight, but rather the moment of the wind pressure on each sail, varying according to its distance from the centre of lateral resistance, has the same effect as a weight on a horizontal line in giving a bending or heeling moment. The next operation is to find the centre of this wind pressure for all the sail area, or, as it is usually termed, *the centre of effort.* This is done by multiplying the area of each sail by the height of its centre from the centre of lateral resistance. Then the sum of all these moments, divided by the sum of the areas of all the sails, gives the vertical height of the centre of effort above the centre of lateral resistance. But it is also necessary to have the fore and aft position of the centre of effort, and this is obtained by multiplying the area of each sail forward of the vertical line through the centre of lateral resistance by the distance of its centre from the vertical line. Having found the sum of all these forward moments, the same operation gives the sum of all the moments aft of the centre of lateral resistance. The difference between the forward and after moments, divided by the total sail area, gives the distance the centre of effort is forward or aft of the centre of lateral resistance. It will, therefore, be on that side on which the moments preponderate. (See position of centre of lateral resistance R, and centre of effort E, in Fig. 110.)

We might just notice here that when the centre of effort is before the centre of lateral resistance, the tendency of the vessel is to fall off from the wind. This is termed *slackness.* On the other hand, when the centre of effort is abaft the centre of lateral resistance, the tendency of the vessel is to fly up to the wind. This is termed *ardency.*

In calculating the position of the centre of effort, only such sail as could safely be carried in a fresh breeze is calculated upon, and the sails are all *supposed* to be braced right fore and aft. A fresh breeze* is reckoned to blow with a force of 4 lbs. to a square foot of canvas. Thus the total sail area, multiplied by the distance of its centre of effort above the centre of lateral resistance, multiplied by 4 lbs., gives the moment of wind pressure in foot-lbs. For example, in Fig. 110, if the sail area is 10,000 square feet, and the centre of effort above the centre of lateral resistance is 50 feet, and the wind pressure on the sails is 4 lbs. per square foot, the heeling moment of the wind pressure is 4 lbs. × 10,000 square feet × 50 feet = 2,000,000 foot-lbs., or $\frac{2,000,000}{2,240} = 892$ foot-tons.

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* The pressure equal to a fresh breeze is taken from the British Meteorological Office Tables.

Now, supposing the displacement of our vessel to be 2,000 tons, and the metacentre above the centre of gravity, G M, to be 2 feet, what will be the angle of inclination with this force of 892 foot-tons wind pressure? We know that the moment to hold a vessel inclined at any angle is the righting lever of stability, G Z, multiplied by the displacement, D, = foot-tons. We have already got the foot-tons of heeling moment—viz., 892, so that

$$\frac{892}{D} = G\,Z = \frac{892}{2,000} = 0{\cdot}44\ G\,Z.$$

We also know that G Z = G M × sine of the angle of heel for small angles, so that $\frac{G\,Z}{G\,M}$ = sine of angle,

$\frac{\cdot 44}{2} = 0{\cdot}22$, sine of the angle of inclination, and reference to the table of natural sines at the end of this book shows the angle of inclination to be about 13°.

The effect of setting top sails and top-gallant sails, and all such light sails, will now be evident.

The higher the sail above the centre of lateral resistance, the more effect it has in producing large heeling moments, though it gives no increased propelling power. Thus, when signs of a squall appear, and all topsails are set, these are taken in first, for two reasons—

1. If the vessel has *a great metacentric height*, and is, therefore, very stiff, when the squall strikes her she offers great resistance to heeling, with the result, that in such a case the topmasts are often carried away, or the sails torn to shreds.

2. If the ship is tender, and has, therefore, *a small metacentric height*, the effect of a squall of wind is to incline her to about twice the angle to which she would have gone if she had steadily and slowly inclined. Indeed, this would happen in any case. Many a vessel has been capsized through no other cause than this. A vessel with heavy yards, &c., is made stiffer by lowering these spars and stowing them on deck. The result is simply to lower the centre of gravity for the whole ship, and give greater metacentric height.

A point deserving of notice here is, that as the vessel inclines, the effect of a horizontal wind pressure will not be so great as in the upright condition, since the surface upon which it blows is at an angle less than a right angle. The same applies to sail which is not braced right fore and aft. However, our reasoning is sufficiently correct for all practical purposes, and the slight error, moreover, is on the safe side. Under such conditions, the angle of inclination is slightly less than it would otherwise be.

Thus far we have simply considered the effect of a certain amount of sail in heeling a particular vessel with a given metacentric height. But let us view the subject from a different aspect—viz., in determining some features in the design to carry a certain amount of sail at a given angle of inclination. From our previous consideration of the causes affecting metacentric height, we find that this may be done in two ways. It is known that great beam produces a high metacentre, and also, that in a deep vessel with comparatively small beam and low metacentre, the centre of gravity can be brought down by arranging the ballast to obtain the position of the centre of gravity required. The opinion is still in some degree prevalent that a vessel with a narrow midship section is better adapted for speed than one with considerable breadth. These erroneous ideas have been entirely upset by the valuable experiments conducted by the late Mr. Froude, who clearly showed that of two vessels of similar length and equal displacements, the one with the greater beam, and consequently of finer ends, was the better design for speed. At the same time, this design of vessel, with good beam and fine underwater form and ends, is the type which can be made stiffest and most capable of carrying great sail area, for it not only sends the metacentre high, but in yachts, by placing the ballast low, the centre of gravity can be brought down.

Frictional Resistance.—From a point of speed, however, it must be remembered that short vessels encounter greater resistance from the friction of the water upon the immersed skin than long ones, *the first* 50 *feet of length being the part which suffers most from frictional resistance.* This is more especially so when high speeds are attained. After this length the particles of water, having partaken of the onward motion of the vessel, naturally offer a diminished resistance. Up to about 8 knots, from 80 per cent. to 90 per cent. of the total resistance is due to skin friction.

The necessity, therefore, of keeping the bottoms of vessels clean is most important, as a rough surface adds immensely to the amount of resistance, a surface of the smoothness of calico offering approximately twice the resistance of a varnished surface;

and, of course, sand about two-and-a-half times the resistance of varnish. Beyond these speeds, other resistances become very important, frictional resistance diminishing to 50 per cent. or 60 per cent. of the total.

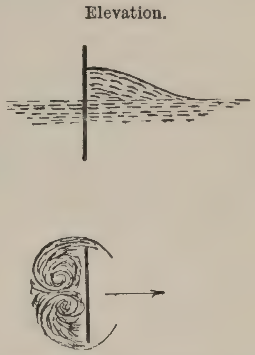


Fig. 111.—Wave and Eddying made by Moving a Flat Board through Water.

Wavemaking Resistance.—This is found most in vessels of bluff form at the ends, simply because, especially at the fore end, the head resistance offered by the bluffness, corresponding to a flat board moved as shown in Fig. 111, causes the water to rise up in front of the vessel, and the making of this wave means expenditure and loss of power. It is not uncommon in vessels of the bluff cargo type, of not more than 9 knots per hour, to create a considerable wave 6 or 8 feet in front of them.

In vessels bluff at the after end, waves are also created at the stern, though not to such a marked extent; but something else occurs which gives rise to another resistance—viz.:—

Eddy-making Resistance.—This is similar to the effect of the flat board moved as shown in Fig. 111. After the water has poured round the edges of the board it eddies behind it, and travels in the direction in which the board is moved. All the energy needed to produce this is loss of power. Just so is it with our actual ship. The eddying water being dead the rudder is rendered less efficient, and if the vessel be a screw steamer the propeller is also less effective; so that while it is most essential for speed to have the entrance of the fore end fine, it is of paramount importance to have the run or the aft end fine, as there is the danger of a double resistance—wave and eddy-making—which for high speeds assumes enormous proportions.

Coming back to the subject of design, let us take a yacht 100 feet long, with a displacement of 200 tons, and a required sail area of 5,000 square feet. This would represent, at the rate of 4 lbs. per square foot, a sail pressure from wind of

$$\frac{4 \text{ lbs.} \times 5{,}000}{2{,}240} = 8{\cdot}9 \text{ tons.}$$

Let the estimated height of the centre of effort above the centre of lateral resistance be 40 feet, then 40 × 8·9 = 356 foot-tons heeling moment. This must be balanced by the stability at, say, a required angle of inclination of 15°.

First, we must find the righting lever of stability at this angle—

$$\text{Displacement} \times \text{lever, or } G\,Z = \text{moment},$$

then, $$\frac{\text{Moment}}{\text{Displacement}} = \text{lever, or } G\,Z\,;$$

therefore, $$\frac{356}{200} = 1{\cdot}78 = G\,Z.$$

The next operation is to find the height of the metacentre, G M, above the centre of gravity, which will give 1·78 = G Z.

The rule is, G M × sine of the angle of heel = G Z,

then $$\frac{G\,Z}{\text{sine of angle}} = G\,M,$$

the sine of $15° = 0{\cdot}258$;

therefore, $$\frac{1{\cdot}78}{0{\cdot}258} = 6{\cdot}9 \text{ feet metacentric height.}$$

In yachts there is the alternative, where the displacements are equal, as to whether it is better to get metacentric height by beam, with more or less draught and less ballast, or by increased depth and draught, and less beam and more ballast. On this point, as the designs of recent fast racing yachts prove, naval architect experts differ in opinion in some degree.

However, in sailing ships, where it is not possible to regulate and fix the centre of gravity as on a yacht, whose conditions are fairly constant, but which on succeeding voyages carry cargoes of varying densities, it becomes necessary to give sufficient metacentric height and stiffness by means of beam.

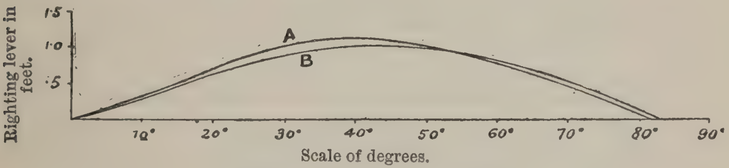
In some cases double bottoms are fitted for water ballast, but this is not the common practice, since when the holds are full and the tanks empty, the effect of the double bottom is to raise the centre of gravity of the cargo, and tend to make the vessel tender. The combined effect of lofty masts and great sail area unite to necessitate greater stiffness.

CHAPTER VI. (Section VIII).

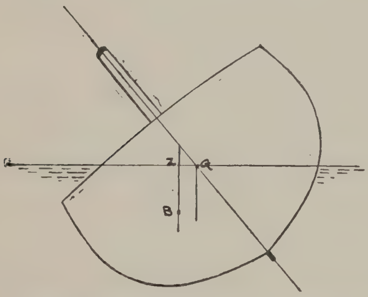
STABILITY INFORMATION.

What stability information should be supplied to a commanding officer?

It would be rather a difficult matter to answer this question to the satisfaction of every naval expert, and non-expert, since the purposes for which vessels are built vary so much in their nature. But it appears that the commanding officer, after making himself thoroughly acquainted with the principles of the subject, and fully aware of the possible exigencies which his vessel may meet, is the fittest and most capable person to decide what information is required. It is scarcely necessary at this stage to state that officers of all vessels do not need the same



A, Curve for fully equipped condition.
B, Curve for coal and stores consumed.



Angle of maximum stability. A, condition.

Fig. 112.—Curves of Stability of a Steam Yacht.

information. In the case of a yacht whose condition is practically constant, the only change arising from the consumption of bunker coal and stores, scarcely any information is required, as such a vessel can be designed and built to fulfil certain conditions and to possess a definite amount of stability. At most, therefore, two curves, showing her righting levers and range, in the light and equipped condition, can be of any value in satisfying her captain of her reserve safety. Fig. 112 represents the curves of a steam yacht 152 feet long, 22 feet beam, and 13½ feet deep.

Then, again, other vessels are built for special trades, and the exact natures and densities of their cargoes being thoroughly understood, the naval architect is able to produce a design such as will ensure certain conditions of seaworthiness in the loaded condition.

But by far the majority of vessels are built to carry miscellaneous cargoes, those known as *tramps* carrying anything and everything, anywhere. So that while it is impossible to design and build a ship specially adapted for every trade, it lies in the power of the naval architect or shipbuilder to provide such information as will greatly help the commanding officer in understanding what condition of loading and ballasting to avoid, and what to adopt, to best make his particular vessel seaworthy. The method of supplying curves of stability adopted by Messrs. J. L. Thompson & Sons, Ltd., of Sunderland, is certainly a most commendable one. Figs. 96 and 97 show sets of curves provided by them for two of their steamers.

In addition to the information on these curves in the case of general carrying vessels, there might be provided with great advantage and profit to the ships' officers the following, viz. :—

(1) *A curve of stability when floating at the load draught* with the least metacentric height compatible with safety, as a guard against making the vessel too tender.

(2) *A curve showing the stability when loaded to the hatches* with the lightest homogeneous cargo likely to be carried of specified density or cubic capacity per ton, with a statement of the amount of ballast to be carried in order to ensure safety and produce the best behaviour. (But it does not follow that the vessel be ballasted down to her load waterline to obtain such a condition.)

(3) *A curve of stability with the heaviest cargo* likely to be carried of specified density or cubic capacity per ton weight, together with a statement of how such cargo should be stowed in the holds and 'tween decks, so as to ensure sufficient stability, and the best behaviour at sea.

(4) *An intermediate curve for a cargo of medium density*, and a

statement of the quantity of ballast if such is required, to produce the best results.

(5) A most important *curve* is that *showing the best condition of a vessel light and in ballast*, with an exact statement of the amount and position of ballast to be carried to ensure such a condition.

In these days, when water ballast is so extensively used, a great amount of ignorance is evinced as to *how* and *where* it should be stowed to secure the desired results. In some cases water ballast is carried only in fore and after peaks, with as little temporary ballast as possible in the holds. The effect of this in straining the vessel has already been pointed out. The commonest method is to fit water ballast tanks throughout the whole or part of the length of the bottom, and in some cases to make these several feet in depth for part of the length, and yet the common practice is to fill them all up when light, regardless of the difference in type, proportions, &c., and the result is that officers complain of their vessel almost rolling her masts overboard. A glance at Figs. 96 and 97 very clearly indicates what would be the probable behaviour of these vessels at sea, light or with their ballast tanks full. Curves A and B show the stability levers of the vessels light, and C and D with the ballast tanks full. In all these cases, and especially in Fig. 97, the levers are very long for small angles of inclination; in fact, the vessels have too much stability, with the natural and consequent result that heavy rolling would most probably be experienced. We are thus driven to the truth that the bottom of the ship is not always the proper place for all the ballast. As previously explained, a better principle sometimes adopted is to fit very deep tanks in the region of amidships, which, while increasing the displacement, also mitigates the evil of excessive stability. It is undoubtedly true that many shipowners are strenuous in their endeavours to procure the most favourable features in their vessels, but at the same time the absurdity of the fact cannot be overlooked that others who are unsparing in lavishing money over the internal arrangements of their vessels in order to secure the greatest comfort for passengers, are yet so utterly regardless of ascertaining the best means of ridding their vessels of the great discomfort caused by excessive rolling.

CHAPTER VI. (SECTION IX.)

CLOSING REMARKS ON STABILITY.

General Results.—Before concluding our considerations of the various aspects of the subject of stability, it may be advisable to gather up, as briefly as possible, a few of the most important facts which have been revealed.

The *centre of buoyancy* is the centre of gravity of the displaced water, at whatever angle the vessel may be inclined, and through which the upward vertical pressures of buoyancy act.

The *transverse metacentre* is the point where the vertical line through the centre of buoyancy for indefinitely small angles of inclination intersects the middle line of the vessel (such middle line being the line through keel and masts), and is also the point above which the centre of gravity must not rise, in order that a condition of stable equilibrium may be maintained. It is influenced chiefly by beam.

The *metacentre* and the *centre of buoyancy* vary in position with every variation of draught, but always occupy the same respective positions at any particular draught. Their exact positions, when floating upright at any draught, are found from curves obtainable from the shipbuilder or naval architect.

The *centre of gravity* is the centre of the total weight (not bulk) comprising a ship and her entire equipment and cargo. It may, therefore, occupy widely different positions for the same draught, according to the high or low positions of the weights carried. The centre of gravity is found by experiment, as previously explained in this chapter.

The distance between the centre of gravity and the metacentre is termed the *metacentric height.*

Metacentric height in feet, multiplied by the sine of any angle not exceeding 10° or 15° for ship-shaped vessels, gives approximately the righting lever of stability, in feet, for that angle. Righting lever in feet, multiplied by displacement in tons, equals righting moment in foot-tons.

Metacentric height, or metacentric stability, is, in present practice, held to be unreliable beyond the small angles previously stated, as it may continue to grow both in the length of the levers and in the extent of the range, or it may rapidly decrease and vanish altogether.

The *lever of stability* can be ascertained at any angle of inclination by finding the position of the centre of buoyancy at that angle. The horizontal distance between the vertical lines through the centre of buoyancy and the centre of gravity indicates the righting lever. If the vertical line through the centre of buoyancy intersects the centre line of the vessel (that is, the line passing through the keel and masts) above the centre of gravity, the lever is a *righting* one; if it intersects below the centre of gravity, the lever is an *upsetting* one.

A diagram, showing the levers of stability at all angles of inclination when in any particular condition, indicating both the angles of maximum levers and vanishing point of stability, is termed a *curve of statical stability*, and is also obtainable from the naval architect or the shipbuilder.

Large metacentric height indicates great *stiffness*, and small metacentric height *tenderness*.

Stiffness can be obtained in designing a ship by increasing the beam, and thereby raising the metacentre; and in an actual vessel already built, by lowering the weights on board and bringing down the centre of gravity.

If the range of a vessel's stability is known at the load draught with a certain metacentric height, any reduction in that height, which can only be effected through the centre of gravity, means reduced range and reduced levers of stability, and any increase produces both increased levers and range.

Similar metacentric heights at different draughts produce widely different conditions of stability.

Freeboard is also a powerful agent in influencing a vessel's stability, but by itself is no guarantee for either the range or the length of righting levers. The greater the freeboard, combined with a fixed position for the centre of gravity and a fixed draught, the longer become the righting levers at considerable angles of inclination, and also the greater the range.

At light draughts, even good metacentric height (such as might be admirably adapted for load draught) and great freeboard, may only produce small range and levers of stability.

Great stiffness creates rapid movements among waves, and tends to heavy rolling, while tenderness conduces to slow, easy movements, and general steadiness.

All vessels endeavour to float among waves in a position square to the wave surface. How far they succeed, depends chiefly upon the ratio of their period of oscillation in still water to the period of the waves among which they are moving.

By a vessel's *period of oscillation* is meant the time taken to perform one complete roll, that is, say from port to starboard, when forcibly inclined in still water. The period for large and small angles of roll is approximately the same.

By the *wave period* is meant the time occupied in the passage of two successive wave crests past a stationary object.

When the period of oscillation is less than half the wave period, the vessel will roll with the waves, approximately maintaining herself square to their surface, being upright at their summit and trough, and at her greatest inclination on the steepest part of the wave slope. This could only be accomplished by vessels of extraordinary beam to depth, and also when the beam is comparatively small in relation to the length of the waves, but is exactly the manner in which a small raft would float among waves.

Although it is most uncommon to find vessels so rapid in their movements as to have their period of oscillation less than the half wave period, it is not so uncommon to find vessels which have been made so stiff as to have a roll period probably half the period of the waves they are likely to fall in with, producing *synchronism* with the waves, or, in other words, keeping time, and thus when at their greatest angles of inclination, they receive the impulse of the wave, and answer by taking a tremendous lurch.

Synchronism may also occur periodically on a series of waves.

When it is remembered that waves in different localities, and at different times, vary both in length and period, it will be seen that it is scarcely possible to always escape the effect of synchronism, however a vessel may be loaded. It should be noted that in vessels made excessively stiff, the probability of synchronism is greatly increased, and on the other hand, with the slow rolling ship, though it is not unlikely that occasionally she may fall in with waves producing the same effect, nevertheless, taking her all round, she is certainly the steadier and more comfortable ship.

Slow rolling motion, which is conducive to steadiness, may be obtained chiefly in three ways:—

1. By small metacentric height.

2. By means of resistance agents on the immersed skin in the form of bilge keels.

3. By winging out the weights from the centre to the sides of the vessel.

The two latter of these are very safe methods, since they make no deduction from the vessel's stability. The first, however, necessitates a correct understanding of the vessels dealt with, for, as previously stated, any reduction of metacentric height produces both shorter levers and range. Moreover, what is safe and good for one ship may be exceedingly dangerous for another, hence the necessity of correct information being provided by the designer, and received by the commanding officer, in order to ensure safety.

Synchronism among waves upon a vessel of very small metacentric height and slow rolling period, may cause her to reach large angles of inclination, and if the levers and range are very short, will greatly increase the possibility of her capsizing.

Bad loading may thus produce both the dangerous extremes—excessive stiffness with heavy rolling, and too much tenderness with great lack of necessary stability.

Synchronism may be destroyed by altering the speed or course.

CHAPTER VII.

TONNAGE.

CONTENTS.—Importance to Shipowners from an Economical Point of View—Under Deck Tonnage—Gross Tonnage - Register Tonnage—Deductions for Register Tonnage—Importance of Propelling Deduction in Steamers—Deep Water Ballast Tanks—Deck Cargoes—Examples of Actual Ship Tonnages—Sailing Vessels—Suez Canal Tonnage—Yacht Tonnage.

MERCHANT VESSELS.

Importance to Shipowners.—Ships' dues, such as pilotage, dock, river, &c., are paid upon the register tonnage. Tonnage is, therefore, a subject of great importance to the shipowner, from an economical point of view. Nevertheless, considerable misunderstanding is prevalent as to what tonnage really is.

Register tonnage does not, as some would imagine, give any idea of the size of a vessel, for, an ordinarily proportioned vessel, 250 feet long, may have a register tonnage of 700, and another of identical proportions may have a register tonnage of only 300, and yet both vessels may have equal displacements. Thus we gather that register tonnage gives no criterion of comparison between one vessel and another as to their dimensions, displacements, or deadweights.

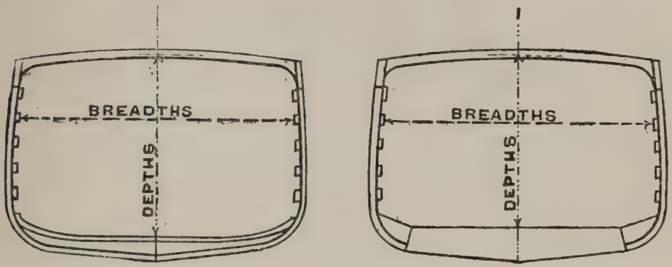
A glance at a Board of Trade Tonnage Certificate for any vessel, or a Register of Shipping, shows three distinct tonnages, viz. :—*Underdeck*, *gross*, and *register*. One ton of under deck, or gross tonnage, is equal to 100 cubic feet of capacity, so that these tonnages may convey some idea of the entire internal capacity of a vessel. Register tonnage, however, is a number having no dependence upon the internal capacity as a whole, as already stated, but is modified by the arrangement of the vessel.

Under deck tonnage is the total tonnage up to the tonnage deck, and is the first part of the vessel measured for tonnage.

Note.—The tonnage deck is the upper deck in all ships which have less than three decks, and the second deck from below in all other ships.

Under deck tonnage is measured as follows :—

If the vessel is constructed with ordinary floors, the *depth* at any part of the length of the vessel to the tonnage deck is measured from the inside of the ceiling upon the floors, for which an allowance of 2½ inches is made, to one-third of the camber of the beam, down at the centre of the beam (see Fig. 113).



FIGS 113, 114.—UNDER DECK TONNAGE; BREADTH AND DEPTH.

Should the vessel be built with a double bottom, the depth is taken from the plating forming the top of the double bottom, to the height as previously described (Fig. 114). In this case no allowance is made for ceiling, whether the vessel has any or not.

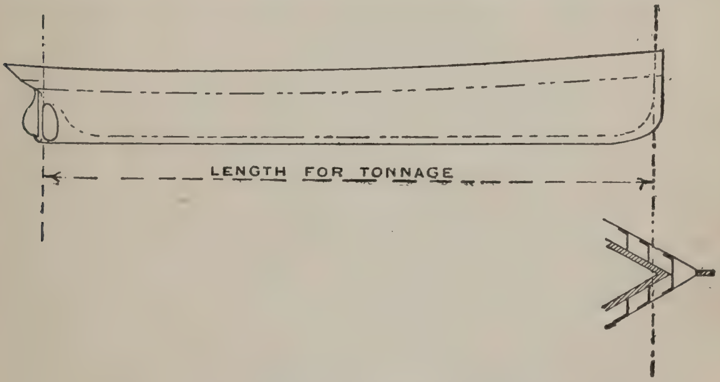


FIG. 115.—LENGTH FOR UNDER-DECK TONNAGE.

Where a vessel is constructed with ordinary floors at one part of her length, and a double bottom at another, the depth for tonnage is taken out to the ceiling in the one case, and to the inner bottom plating in the other, the tonnage in the range of each part being taken out separately.

The tonnage measurements for *breadths* are taken from the inside of the sparring in the hold, 2½ inches being allowed if the vessel is so fitted. Sometimes, instead of wood sparring, half round iron is rivetted to the reverse frames, especially in colliers. In this case the breadths are taken from the half round iron, side to side. Where neither sparring nor half round iron is adopted, the breadths are taken to the reversed frames, or to the inside of the framing.

The length for under-deck tonnage is measured from the points at the extreme ends of the vessel where the inside lines of the sparring unite, or in the case where no sparring of any sort is fitted, to the points, where lines forming the inside of the framing unite (Fig. 115).

The Board of Trade Surveyor then measures the inside of the vessel to the positions indicated, and by means of Simpson's rules the cubic capacity in feet is found. If anything, this method of finding the cubic contents by these rules, gives the capacity rather under the actual, so that the difference is slightly in favour of the shipowner. In the case of vessels of the raised quarter-deck type, the tonnage deck is the main deck, and where the main deck stops, and the raised quarter deck begins, the line of the main deck is taken as the tonnage deck, as shown in Fig. 116, and the capacity of the raised quarter deck is computed separately.

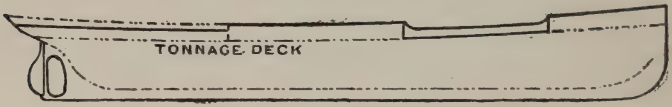


Fig. 116.—Tonnage Deck.

Gross tonnage comprises the under-deck tonnage, together with all enclosed erections in the form of poops, bridges, forecastles, spar decks, awning decks, raised quarter decks, deck houses, engine and boiler casings, &c. The only exception to this rule is that the crew's galley, crew's w.c.'s, and companions are usually omitted in the calculations for tonnage.

By enclosed erections is meant spaces closed in on all sides; for example, poops with closed fronts of wood or iron, bridges with closed ends, and forecastles with closed ends. Open-ended poops, bridges, forecastles, or deck shelter, used only for the protection of passengers from the sea and weather, are not included in the gross tonnage. Should, however, any houses or store rooms of any kind be constructed beneath an open-ended erection, they are reckoned in the gross tonnage.

Register tonnage is obtained from the gross tonnage after certain allowed deductions have been made, and as the various dues and charges are levied upon this tonnage, the nature of the deductions will form the subject of our next consideration. First of all, it must be remembered that no deduction for any space whatever is made, unless it be first included in the gross tonnage. The deductions allowed, and the conditions required to ensure the same, are as follows:—

1. *Crew Space.*—This must be available for the proper accommodation of the men who are to occupy it, protected from sea and weather, properly ventilated and lighted; must contain 72 cubic feet and 12 square feet of floor room per man; must be occupied exclusively by the crew and their personal property in use during the voyage, and reasonable w.c.'s provided.

2. *Master's Accommodation.*—This space must be used exclusively by him, and be reasonable in extent.

3. *Engineers' and Officers' Accommodation.*—This includes berths, mess rooms, and reasonable w.c.'s used by them alone.

Note.—A mess room, used by both the captain and the officers, is not deducted for register tonnage.

4. *W.C.'s.*—In passenger steamers one w.c. for fifty passengers, and not more than twelve w.c.'s altogether, are allowed.

5. *Sail Room.*—This refers to sailing ships only, and on condition that the room does not exceed 2½ per cent. of gross tonnage. If it does exceed this percentage, 2½ per cent. only of the gross tonnage is allowed.

6. *Boatswain's Store.*—10 to 16 tons is the usual allowance, according to the size of the vessel.

7. *Wheel Room, &c.*—Space occupied exclusively for the working of the helm, the capstan, the anchor gear, or for keeping charts, signals, and other instruments of navigation.

8. *Donkey boiler*, when not connected with the engine room.

9. *Deck shelter* for passengers, when used only for this purpose, and closed at the ends. A sketch of this space should be submitted to the Board of Trade, and it might possibly be excluded from the tonnage altogether.

10. *Propelling Deduction.*—The propelling space includes engine and boiler rooms, tunnel, donkey boiler space, if connected with, and forming part of the main engine space, light, and air space. This last comprises all space over or about engines and boilers of reasonable extent, and used exclusively for the admission of light and air; it must also be safe and seaworthy. Any such space admitting light and not air, or air and not light, will not be included in the deduction. No stores

of any sort must be carried in the propelling space. Store rooms or bunkers at the sides of the engines or the boilers will be excluded in making up this deduction. These restrictions being fully complied with paddle steamers with a propelling space of from 20 to 30 per cent. of the gross tonnage will have an allowance for propelling space of 37 per cent. of the gross tonnage. Screw steamers with a propelling space of from 13 to 20 per cent. of the gross tonnage will have an allowance for propelling space of 32 per cent. of the gross tonnage. If the propelling space is less than 20 per cent. in paddle vessels, and 13 per cent. in screw vessels of the gross tonnage of the ship, the Board of Trade have the option of either estimating the deduction at 37 per cent. in the case of paddle vessels, and 32 per cent. in screw steamers of the gross tonnage, or, if they think fit, allowing in the case of paddle vessels, once and a-half the propelling space tonnage, and once and three-quarters the propelling space in screw vessels. The latter method is usually adopted.

When, however, the propelling space amounts to 30 per cent. or more of the gross tonnage in the case of paddle vessels, and 20 per cent. or more of the gross tonnage in the case of screw steamers, the owner has the option of having the deduction estimated according to the 37 or 32 per cent. respectively, or, if he desires, the deduction may be once and a-half the propelling space in paddle vessels, and once and three-fourths the propelling space in screw vessels. The question arises as to which of these methods is more advantageous to the shipowner. Let us see. Suppose a paddle vessel has a given gross tonnage of 100, and a propelling space of $30\frac{1}{2}$ tons. If the 37 per cent. method is adopted, the deduction will be 37 tons. If the once and a-half method is chosen, the deduction will be $30\frac{1}{2} + 15\frac{1}{4} = 45\frac{3}{4}$, which is certainly preferable from an economical point of view to the 37 tons deduction. Again, let the gross tonnage of a screw steamer be, say, 100, and the propelling space $20\frac{1}{2}$, which proportion is not at all uncommon in vessels of average speed. Choosing the deduction of one and three-fourths of the propelling space, since the propelling space is over the 20 per cent., the actual deduction would be $1\frac{3}{4}$ of $20\frac{1}{2} = 35\frac{7}{8}$, which again is considerably more preferable than 32 as a deduction, and thus when we include the other deductions already enumerated, crew space, &c., we can easily understand how, in some vessels of comparatively large dimensions, with large propelling space, the register tonnage is abnormally small. Take a fine high speed passenger paddle steamer with a gross tonnage of, say, 100, and a large propelling space (situated amidships, and occupying the bulkiest part of the vessel) of, say, 40 tons of actual cubic measurement.

The deduction would be once and a-half of 40 = 60 for propelling space, which without the other deductions is more than one-half the gross tonnage. A similar screw steamer with a gross tonnage of, say, 100, and propelling space by actual measurement of 30 tons would have a deduction of once and three-fourths of 30 = 52½ for propelling space alone, also more than one-half of the gross tonnage. These are by no means exaggerated examples. It should be noted, that the higher the actual propelling space tonnage is above the 30 per cent. of gross in paddle vessels, and 20 per cent. of gross in screw vessels, the greater is the proportion of deduction.

In the ordinary tramp type of cargo steamers of comparatively low speed, and where all available space is required for cargo and bunkers, in many cases it might be found unwise to endeavour to get a propelling space of 20 per cent. of the gross tonnage, as this would require a sacrifice of too much space, which might be better utilised for bunkers or cargo. In vessels of this type, to obtain the 20 per cent. generally implies that it is only done by fitting no side bunkers in engine or boiler space, or at most, small pockets. However, this is a point needing the careful consideration of the shipowner or designer of the vessel.

From the study of these deductions, it is evident that the Board of Trade have given every encouragement to the providing of suitable accommodation, or at least, reasonable berthing for officers, and crew especially, for perhaps of all the comfortless and forbidding human habitations, the forecastles of some vessels would claim a foremost place. We have also seen the advantage gained by providing, when practicable, spacious and well-ventilated engine and boiler rooms.

Before giving a few examples of the tonnage of actual vessels, it may be well to point out one or two items from the Board of Trade Tonnage Rules, which might be misunderstood.

In vessels constructed with double bottoms for water ballast, the measurement for tonnage is only taken from the plating of the inner bottom, when the space between the inner and the outer bottom plating, *of whatever depth*, is certified by a Board of Trade Surveyor to be not available for the carriage of cargo, stores, or fuel.

Deep Water Ballast Tanks.—Should, however, a vessel be built with a raised platform in the bottom, or in other words, a deep tank, thereby making it *possible* for cargo, stores, or fuel being carried in this space, the depths for tonnage are taken down through the platform, or the deep tank, to the height of the ordinary floors, deducting the average thickness of ceiling.

Fore and after peak tanks, though constructed and intended only for water ballast, are *included* in the measurement for tonnage, the depths being taken down to the top of the floors. By fitting floors, or partial floors, from the deck or top of the peak tank downwards, the tank is excluded from the tonnage.

Deck Cargo.—Ships engaged in the foreign trade, carrying deck cargoes in the form of timber, &c., in spaces not included in the measurement of the tonnage of the vessel, have the space occupied by such cargo measured when the vessel arrives in port, and the cubic capacity being computed, and divided by 100, gives the tonnage which is deemed register tonnage, and charged upon accordingly. Between the 31st of October and the 16th of April, vessels from any port out of the United Kingdom are not allowed to carry deck cargoes exceeding three feet in height above the deck, under penalty.

Examples.—

EXAMPLE I.

Steam screw collier, 228 feet long. Raised quarter-deck type.

Gross Tonnage—

Under deck tonnage,	680
Erections—	
Raised quarter deck,	60
Poop,	47
Bridge,	120
Lamp room under open forecastle,	5
Casings and deck houses on bridge,	36
Excess of hatches over $\frac{1}{2}$ per cent. of gross tonnage,	16
Total,	964

Propelling space, 210 = 21·7 per cent. of gross tonnage, therefore the 1$\frac{3}{4}$ of actual propelling space is chosen.

1$\frac{3}{4}$ of 210 = 367·5.

Had the propelling space been less than 20 per cent. of the gross tonnage the deduction would only have been 32 per cent. of the gross tonnage = 308·4, which makes a difference in the ultimate register tonnage of 367·5 - 308·4 = 59·1. In tramp vessels of this type it is not very usual for the propelling space to exceed the 20 per cent. of gross tonnage. However, it will be seen how spacious light and air space in the casings above the tonnage deck will greatly assist towards this end. Sometimes boiler casings are made wide enough for unshipping the boilers without interfering with the deck.

The deductions for the register tonnage in this vessel were as follows :—

Propelling space, . . .	367·5
Chart room, ...	5
Bridge accommodation for officers,	54
Crew space, ...	23
Boatswain's store, . . .	10
Total, . . .	459·5

Gross tonnage, .	964
Total deductions, .	459·5
Register tonnage, .	504·5

EXAMPLE II.

Passenger steamer, 200 feet long, with a combined poop and bridge, and a topgallant forecastle.

In vessels of this type, where a high speed is required, the propelling space usually exceeds the 20 per cent. of gross tonnage considerably, as seen by the following figures :—

Under deck tonnage, ...	530
Poop, bridge, and forecastle, . .	285
Deck houses and casings, . . .	40
Gross tonnage, . .	855

Propelling space measured 235 tons = 27 per cent. of gross tonnage.

The allowance, therefore, is $1\frac{3}{4}$ of 235 = 411 (32 per cent. of gross = 273·6).

Deductions for register tonnage are as follows :—

Propelling space, ...	411
Crew, ...	40
Passengers' w.c.'s, ...	4
Master's accommodation and chart room,	7
Boatswain's store, ...	10
Total, ...	472

Gross tonnage, .	855
Total deduction,	472
Register tonnage,	383

EXAMPLE III.

Sailing ship, 320 feet long, with a poop and a topgallant forecastle.

Under deck tonnage,	2900
Poop,	110·5
Forecastle,	20·4
Houses on deck,	8·0
Gross tonnage,	3038·9

Deductions for register tonnage are as follows:—

Crew space,	115·9
Boatswain's store,	15
Donkey boiler house,	14
Sail room,	20
Total,	164·9

Gross tonnage,	3038·9
Total deduction,	164·9
Register tonnage,	2874

In sailing vessels we always find the gross tonnage large as compared with steamers. This is accounted for by the fact, that there being no engines and boilers, and, therefore, no propelling space deduction, the entire hold space is at the disposal of cargo.

Suez Canal Tonnage.—For ships intended to navigate the Suez Canal, a special tonnage certificate is required, since the method of computing the nett register tonnage differs in a few of its details from the ordinary system.

The under-deck tonnage is precisely the same.

The gross tonnage includes, in addition to the under-deck tonnage, every permanently-covered and closed-in space on or above the tonnage deck without any exception. Such a space as a shelter under a shade deck, open at the sides and supported by means of stanchions, would therefore be excluded from the gross tonnage.

The deductions for nett register tonnage are as follows:—

1. *Propelling Space.*

The owner has the option of either of the following methods:—

(*a*) The deduction may be one and three-fourths of the actual engine room as measured for screw steamers, and one and a-half for paddle vessels; or,

(*b*) The actual measurement of the engine room, together with the actual measurement of the permanent bunkers.

Note.—Bunkers which are portable, or from which coal cannot be directly trimmed into the engine room or stokehole, or into which any access can be obtained otherwise than through the ordinary coal shoots on deck, and from doors opening into the engine room or stokehole, are not included in the measurement in paragraph (*b*). In no case, except in that of tugs, is the actual engine-room allowance to exceed 50 per cent. of the gross tonnage of the ship.

2. *Crew space*, with the exception of the master's accommodation and stewards' berths. Should there be a doctor's cabin, this space will only be deducted when the doctor himself is on board.

Not more than 4 tons are allowed for an officers' and engineers' mess room.

For a second mess room for boatswain, carpenter, &c., not more than 2½ tons are allowed.

Should passengers be carried and no eating room be provided for them, no deduction whatever is allowed for officers' and engineers' mess room.

When no passengers are carried, a bathroom, used entirely for the officers and engineers, is reckoned as a deduction, and even when passengers are on board, if there be more than one permanent bathroom, one of such spaces is subject to deduction, being considered as specially for the use of officers and engineers.

Not more than 2 tons are allowed for a bathroom.

3. *W.C.'s*, exclusively for the use of the crew.

4. *Wheel house*, *chart house*, *winch house*, *look-out house*.

Should the captain be lodged in the chart room, an allowance of 3 tons is made for the space occupied by charts.

5. *Cooking houses*, used only for the crew. Passengers' galleys are therefore not deducted from the gross tonnage.

6. A *donkey boiler house* in a closed space on the upper deck. Should, however, the donkey boiler be used for hoisting cargo, no deduction is allowed.

In no case is the sum total of these deductions, with the exception of propelling space, to exceed 5 per cent. of the gross tonnage of the ship.

No deduction is made for passengers' accommodation, captain or passengers' w.c.'s or lavatories, nor luggage store rooms.

In no case is any space to be deducted from the tonnage, which is not first included in the gross tonnage.

YACHTS.

Yachts are measured for tonnage in exactly the same manner as ordinary merchant vessels, the same deductions being allowed for register tonnage.

For example, take a yacht 180 feet long. The gross tonnage would be comprised as follows :—

Under deck tonnage,	520·5
Deck houses,	10
Monkey forecastle,	6·1
Total,	536·6

Deductions for register tonnage—

Propelling space,	220·6
Crew space,	49·5
Total,	270·1

Gross tonnage,	536·6
Total deduction,	270·1
Register tonnage,	266·5

Measurement of Yachts for "*Royal Thames*" *Yacht Club.*

Measure the length of the yacht in a straight line at the deck from the fore part of the stem to the after part of the stern post. From this length deduct the extreme breadth. If the vessel be iron or steel, this breadth is taken over the plating, and if composite or wood, over the planking. The remainder is the length for tonnage. If there be any projection of the stem or stern posts beyond this length, such projection must be added to the length already mentioned for tonnage purposes. Multiply the tonnage length by the extreme breadth, then that product by half the extreme breadth, and divide the result by 94. The quotient will be the tonnage.

Example.—Steel yacht 200 feet extreme length over stem and stern posts 28 feet extreme breadth.

$200 - 28 = 172$ feet, length for tonnage.

$\frac{172 \times 28 \times 14}{94} = 717\frac{26}{94}$ tonnage Thames measurement.

CHAPTER VIII.

FREEBOARD.

CONTENTS.—Definition—Method of Computing Freeboard—Type of Vessel—Nature of Deductions, and Additions to Freeboard—Examples of Estimating Freeboard for Different Types of Vessels.

Definition.—By the term *Freeboard* is meant the height of the side of a ship above the waterline at the middle of her length, measured from the top of the deck at the side. Should a wooden deck be laid, it is taken from the top of the wooden deck. In Fig. 3, x shows the amount of freeboard, which, as will be observed, is 2 feet.

Buoyancy, Structural Strength, Stability, and Freeboard are subjects closely related to each other, indeed, the latter depending almost entirely upon the other three. Hence the necessity, in order to deal intelligently with freeboard, that the reader should make himself acquainted with the contents of Chapters III. to VI. inclusive.

Freeboard is given to a vessel as a margin for safety. For instance, it would be possible for a ship to float with her deck edge level with the water; but in such a condition, having no reserve buoyancy she possesses no rising force, and would, therefore, be submerged beneath every wave, to say nothing, moreover, of the possible effect of such a condition upon her stability.

The amount of freeboard for a particular vessel is modified by the type, structural strength, erections on deck, sheer, camber, &c. It must be borne in mind, however, as previously shown, that such freeboard can only fully perform its chief function, and be a real resource of safety, after a proper adjustment of cargo has been carried out in the operation of loading. The effect of freeboard on stability has already been dealt with in Chapter VI.

Flush-decked steamers, other than spar and awning-decked, and equal in structural strength to 100 A1 at Lloyd's, or equivalent strength at Bureau Veritas, or the British Corporation or other classifying association, require from about 20 per cent. to 35 per cent. reserve buoyancy, according to their dimensions.

This enables a vessel of suitable proportions to carry with safety a deadweight for which her structural strength is adapted, and to endure without damage the severe strains incurred when among waves, already discussed in Chapter IV.

Therefore, all vessels below the standard of the one-, two-, and three-deck type in structural strength, are compelled to carry a smaller deadweight in proportion to their dimensions, with the result that they have increased reserve buoyancy, and, consequently, increased freeboard. Hence the spar-decked vessel, as will be seen further on, requires a larger percentage of reserve buoyancy than the one-, two-, and three-deck vessel; and the awning-decked a larger percentage of total reserve buoyancy than the spar-decked one, which results in both cases in providing increased freeboard. Sailing vessels require rather more reserve buoyancy than steamers.

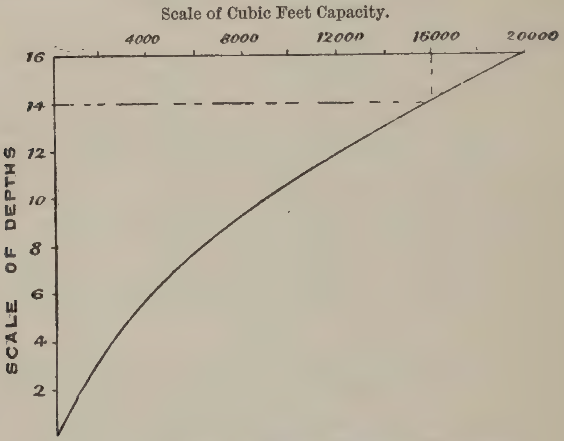


FIG. 117.—CURVE OF CUBIC FEET OF CAPACITY.

An examination of the Board of Trade Tables for such vessels shows that this is the standard worked upon, the aim being to give a freeboard such as will secure the stipulated amount of reserve buoyancy, and thus give to vessels of suitable dimensions sufficient strength for the total weight, including cargo, to be carried, and the rising power and stability (when properly loaded) requisite, when exposed to heavy weather, to ensure safety.

Now, suppose we had a flush-decked vessel, classed 100 A1 at Lloyd's, to which we wished to assign a freeboard producing 20 per cent. reserve buoyancy. To find this accurately, it would be necessary to construct a curve of capacity, identical in its construction with a displacement curve, except that it shows the internal volume up to the deck, and instead of a scale of tons at the top, the scale would represent cubic feet of capacity.

Fig. 117 represents such a curve for a vessel 16 feet depth moulded. It, therefore, comprises the total buoyancy of the vessel up to the deck. This is found to be, say 20,000 cubic feet total buoyancy. 20 per cent. of 20,000 = 4,000 cubic feet to be left above the load waterline = reserve buoyancy.

20,000 − 4,000 = 16,000 cubic feet from the keel to the load waterline. This equals the vessel's load displacement, which gives by the scale a draught of 14 feet, and a freeboard of 2 feet.

But, as is evident, this method entails considerable labour, and would necessitate a copy of the vessel's lines being supplied to the Board of Trade or Registration Society fixing the freeboard, and, therefore, in order to obviate this, another method is adopted, which, though not strictly accurate, is sufficiently correct for all practical and working purposes.

In the last chapter we saw how the Board of Trade Surveyor measured the vessel for tonnage, and the results obtained provide the means of estimating the requisite freeboard.

In Chapter I. it was shown how coefficients of fineness of displacement were obtained, and in a similar manner a coefficient of fineness is obtained from the tonnage under the upper deck, and this, combined with the dimensions of the ship, as will be explained, serves the same practical purpose, in referring to the Freeboard Tables, as would the actual volume of the ship.

The coefficient of fineness is ascertained as follows:—For one-, two-, and three-deck, and spar-decked vessels, divide 100 times the total tonnage (1 ton measurement being 100 cubic feet) below the upper deck (exclusive of any deductions) by the product of the extreme length over the stem and the stern posts on the load waterline, the extreme breadth over the plating, and the depth of the hold.* In awning-decked vessels, divide the tonnage to the main deck, by the product of the length, the breadth, and the depth of the hold to the main deck. In the case of vessels built with cellular double bottoms, a modification or correction has to be made in estimating the coefficient. It should, however, be remembered that the coefficient obtained is that of a vessel built with ordinary floors.

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* The depth of hold used in ascertaining the coefficient of fineness is taken to the top of the ceiling in iron and steel sailing vessels, and to the top of the floors in steamers.

As an example, the tonnage under the upper deck of a certain vessel is 78·4

$78{\cdot}4 \times 100 = 7{,}840$ cubic feet.

The length is 100 feet,
The breadth extreme is 16 feet,
The depth of hold is 7 feet,
$100 \times 16 \times 7 = 11{,}200.$

$$\frac{7840}{11200} = 0{\cdot}7 \text{ Coefficient of fineness,}$$

and this coefficient is that used, in conjunction with the depth, to find the freeboard for this particular vessel from the Tables.

The greater the depth of the vessel, the greater the freeboard. The depth from which the freeboard, as ascertained by the Tables, is measured, is the moulded depth, which is taken from the top of the keel to the top of the upper deck beam at the side, at the middle of the length. When a wooden deck of extra thickness is fitted, the excess of thickness is added to the moulded depth, and the freeboard taken upon this new depth. Now, as we have already pointed out, the structural strength is a most important consideration in determining freeboard, the strongest ship with suitable proportions having the least freeboard. The strongest vessel is the one-, two-, and three-deck type, classed 100 A1 at Lloyd's, or any other vessel, classed or unclassed, but of equivalent strength. Next, we have the spar-decked, and, lastly, the awning-decked vessel.

In assigning freeboard, the term "spar-decked vessel" applies to all vessels equal to, or in excess of, the strength of Lloyd's Spar-deck Rule, but do not reach the structural standard of the three-deck requirements. The freeboard, therefore, depends upon their strength. The standard height for a spar-deck is 7 feet; therefore, since the freeboard is measured from the spar-deck, it will be increased if the 'tween deck height is more, and decreased if it is less than 7 feet.

In like manner, an awning-decked vessel is one equal to, or exceeding Lloyd's structural requirements for awning-decked vessels, but which does not reach the standard for the spar-deck type. In this case also, the freeboard varies with the strength. When the strength of the superstructure above the main deck is less than is required by Lloyd's 100 A1 Awning-deck Rule, the freeboard is increased. The awning deck may, therefore, be classed as simply an erection above the main deck, and since the freeboard is measured from the main deck, no modification is necessary in respect to the height of the awning deck above the main deck. The freeboard of awning-decked vessels classed 100 A1 at Lloyd's is approximately one-twelfth the moulded depth of the vessel less than would have been required had it been built to the three-deck Rule, and flush decked.

No account is taken of erections above the awning deck of vessels of this type. This also applies to spar-deck vessels with but one exception. Since the longitudinal strains of vessels are greatest in the region of amidships, it follows that any efficient erection over this part of the length must add greatly to the strength. Such an erection receives full credit in assigning freeboard in the three-decked heavy deadweight carrier. A similar erection in the form of an efficient bridge on a spar-decked vessel, extending over and protecting the engine and boiler openings for at least two-fifths of the vessel's length, also receives recognition on account of its addition to strength and protection, though not in so great proportion as in the three-decked type. Thus such an erection on a spar-decked vessel of 20 feet moulded depth to main deck, merits a reduction of 3 inches on the freeboard.

For the sake of comparison, let us see the differences of freeboard in a vessel of each of these types—three-decked, spar-decked, and awning-decked, classed 100 A1 at Lloyd's. Let the length in each case be, say, 300 feet, the coefficient of fineness ·7, and the depth to main, spar, and awning deck 25 feet, the spar and awning deck each being 7 feet above the main deck.

The vessel of the first type would have a freeboard of	5 feet 0½ inches.
The spar-decked would have a freeboard of . .	6 ,, 2 ,,
The awning-decked would have a freeboard of .	8 ,, 7¼ ,,

But even after the coefficient of fineness is found, there are certain modifications to be carried out before the exact freeboard is arrived at, and these modifications will next be dealt with.

Let it be understood that only vessels equal in strength to Lloyd's 100 A1 will be considered. Vessels below this standard have increased freeboard:—

1. In spar-decked vessels, having iron-spar decks, and in awning-decked vessels having iron main decks, the freeboard required by the tables should be measured as if those decks were wood-covered. Also, in vessels where $\frac{7}{10}$, or more, of the main deck is covered by substantial enclosed erections, the freeboard found from the tables should be measured amidships from a wood deck, whether the deck be of wood or of iron. In applying this principle to vessels having shorter lengths of substantial enclosed erections, the reduction in freeboard, in consideration of its being measured from the iron deck, is to be regulated in proportion to the length of the deck covered by such erections. Thus, in a vessel having erections covering $\frac{6}{10}$ of the length, the

reduction is $\frac{6}{10}$ of $3\frac{1}{2}$ inches (the thickness of the wood deck), or 2 inches.

2. In flush-deck vessels of the one-, two-, and three-deck type, or those with erections extending over less than $\frac{4}{10}$ of the length, having iron upper decks, and not sheathed with wood, the advantage of having the actual moulded depth reduced by the usual thickness of a wood deck is allowed, a slightly reduced freeboard being thereby obtained. Thus, a vessel of this type with 19 feet 10 inches moulded depth, with no laid wood deck, would be reckoned as 19 feet 6 inches depth in the tables. Taking the coefficient of fineness of this vessel at ·7, referring to the freeboard tables, the freeboard at 19 feet 10 inches depth would have been 3 feet $7\frac{1}{2}$ inches, where, owing to the reduction of the depth to 19 feet 6 inches, the freeboard is 3 feet $6\frac{1}{2}$ inches, an inch reduction being obtained, which may mean an increase in the displacement, and thereby an increase in the deadweight of 12 or 14 tons.

3. *Correction for Length.*—The freeboard tables show that in addition to the coefficient given with every depth, a fixed length is assigned. For example, a vessel with a coefficient of 0·7, and a depth of 16 feet, a length of 192 feet is assigned, but if the length of our vessel with the same coefficient and depth be, say, 212 feet, a correction must be made for the additional 20 feet of length. Wherever the standard length is exceeded, the freeboard is increased, and wherever it is less the freeboard is diminished. The greater the proportion of length to depth, the greater the freeboard. The correction varies from about 1 to 2 inches for a change of 10 feet in length. In the case before us, the correction is 1 inch per 10 feet, and thus for 20 feet it is 2 inches, which has to be added to the specified freeboard in the table. Had the vessel been 10 feet less than 192, the freeboard would have been reduced by 1 inch. The reason for this is easily understood when we remember that the vessel with greatest depth to length is the one most capable of resisting longitudinal bending, and therefore best adapted to carry the most deadweight. Where, however, steam vessels with topgallant forecastles, having long poops or raised quarter decks connected with bridge houses, the whole extending over $\frac{6}{10}$, or more, of the length of the vessel, the correction for excess of length should be half that specified in the tables; so that if the vessel we have taken as an example complied with these conditions, the freeboard would only have been increased by 1 inch, simply because with so great a length of substantial erections, the vessel has practically been increased in depth, and consequently the proportion of depth to length is decreased.

The correction for length in spar-decked vessels varies from about 1 to 2 inches per 10 feet, and for awning-decked vessels from $\frac{1}{2}$ to 1 inch.

4. *Sheer.*—The Board of Trade specify a mean sheer for all types of vessels. Mean sheer is the sum of the sheers at the ends of the vessel, or at whatever part of the length it is specified, divided by 2 (see Fig. 13).

Any increase in the mean sheer means an increase in the reserve buoyancy, and exactly where it is much needed—viz., at the ends, giving additional rising power when the ship dips into the trough of a sea, not to mention the increase of freeboard. This excess of buoyancy is recognised by the Board of Trade, and a deduction allowed in the freeboard according to the amount of the excess of sheer.

For all flush-decked vessels, the mean sheer is found by dividing the length by 10, and adding 10 to the result. Thus a vessel 300 feet long will have a mean sheer of $\frac{300}{10} + 10 = 40$ inches.

Flush-decked vessels of the one-, two-, and three-deck type, with or without a short poop, a topgallant forecastle, and a bridge house completely closed in at the ends, or a long poop, or a raised quarter deck connected with an efficiently closed-in bridge house, where the sheer is greater than in the Table, and is of a gradual character, the reduction in freeboard is found by dividing the difference between the actual sheer and the mean sheer provided for in the Table, by 4. For example, a vessel 300 feet long, with a mean sheer of 46 inches, has a reduction in the freeboard of $\frac{46 - 40}{4} = \frac{6}{4} = 1\frac{1}{2}$ inches. No allowance is given to spar- and awning-decked vessels for excess of sheer; but in any of these types, where the actual mean sheer is less than the mean sheer by the rule, the difference divided by 4 gives the increase of freeboard required for reduced reserve buoyancy.

Line 1 in the Table (p. 216) is for vessels having short poops or forecastles only, or when in addition, there is a bridge house with alleyways open at one or both ends. In these vessels the important point is not the amount of sheer at the ends of the vessel, for great additional buoyancy is given there already by the erections, but over the length uncovered by substantial erections. Therefore, in this particular case, the sheer is measured at one-eighth the vessel's length from stem and stern. One-fourth the difference between the mean sheer and the actual is approximately the amount of increase or decrease of freeboard, as the case may be.

Length over which Sheer is Measured.

	100	150	200	250	300	350	400
	Mean Sheer in Inches over the Length specified.						
No. 1, . .	14	18	22	26	30	34	38
No. 2, . .	14½	18½	23	27	31	35½	40

Line 2 in the Table is for vessels having short forecastles only, and in this case the sheer is measured at points (1) one-eighth from the stem, and (2), at the stern post, and correction for additional sheer is made as in the previous case.

Note.—In flush-decked vessels, and in vessels having short poops and forecastles, the excess of sheer upon which an allowance is made is not more than one-half the total standard mean sheer for the size of the ship.

5. *Round of Beam.*—The stipulated round of midship beam is a quarter of an inch to the foot. Here, again, any excess in the round of beam means an increase of reserve buoyancy, and an allowance is made in the freeboard. When the round of beam in flush-decked vessels is greater or less than that given by the Rule, divide the difference in inches by 2, and diminish or increase the freeboard accordingly by this amount.

Example.—The beam of a vessel is 40 feet, and the round of beam as measured is 12 inches. This is 2 inches more than is required by the Rule, therefore $\frac{2}{2} = 1 =$ amount of decrease of freeboard. Where the deck is partially covered with erections, the amount of the allowance for round of beam depends upon the extent of the upper deck uncovered.

This rule for round of beam does not apply to spar- and awning-decked vessels.

6. *Corrections for Erections on Deck.*—By erections on deck is meant all closed-in structures erected above the upper deck of vessels built to the one-, two-, or three-deck rule,—for example, bridges, poops, forecastle, raised quarter decks, partial awning decks, &c. Now, erections such as those enumerated add greatly, according to their proportions, to the reserve buoyancy, and, as in the case of sheer and camber, the merits of the values of these erections and additions to the reserve buoyancy and structural strength are fully considered by the Board of Trade, and deductions in the freeboard allowed accordingly. In assigning allowances for erections, the complete awning deck is the standard worked from.

As has already been pointed out, in taking out the freeboard for a vessel with an awning deck, the coefficient of fineness and the depth are both taken to the main deck, and not to the awning deck, and the freeboard is assigned and measured down from the main deck. The awning deck thus comes to be what might be termed a complete erection, extending all fore and aft, and covering the main deck. All other erections partially covering the vessel have their deductions on the freeboard made as a fractional part of a percentage of the allowance for a complete awning deck. The reader will easily see that a complete erection such as an awning deck is always better than a partial one, comparing length for length; for instance, an erection covering three-fourths of the vessel's length cannot be taken on equal merits with three-fourths of the awning deck, since it is evident that a well has been created on the weather deck in some part of the vessel's length, forming a break in the longitudinal strength of greater or less importance, and a means thus provided, to some extent, for lodging seas on board, or the possibility created of bulkheads being damaged, &c., therefore, three-fourths' erections do not receive the same credit as three-fourths of the awning deck, but a less fractional part. Again, the allowance varies with the nature of the erections. This we shall endeavour to show by arranging the erections according to their respective values.

Taking a vessel 204 feet long, and, therefore, with an awning deck of the same length, we shall see, by the allowances made for the various erections, how much of the 204 feet of awning deck is credited for at the rate of such allowances. This, it is hoped, will better enable the reader to grasp the comparative values of the erections.

Let the moulded depth of the vessel be 17 feet, and the coefficient of fineness ·7.

The freeboard, had the vessel been flush-decked, to the two-deck rule would have been 2 feet 10½ inches.

The freeboard, had the vessel been awning-decked, would have been 1 foot 4 inches.

2 feet 10½ inches − 1 foot 4 inches = 1 foot 6½ inches = 18½ inches,

this difference being the allowance for the awning deck.

Note.—For a raised quarter deck, 4 feet high, and connected with a bridge house, covering the engine and boiler openings with an efficient bulkhead at the fore end, the allowance is made as though it were a part of the actual bridge, and equal in height. A decrease is made in the deduction, if the raised quarter deck extends over the engine and boiler openings, or if it is less than 4 feet high.

The deductions for erections are as follows:—

1. When the combined length of poop, or raised quarter deck, connected with a bridge house covering in the engine and boiler

openings, and with an efficient bulkhead at the fore end, and topgallant forecastle is—

(*a*) $\frac{9}{10}$ of the length of the vessel,
the deduction is $\frac{85}{100}$ of the allowance for a complete awning deck. Freeboard is $\frac{85}{100}$ of $18\frac{1}{2}$ inches = $15\frac{3}{4}$ inches, and is in proportion to an awning deck 192·5 feet long.

(*b*) $\frac{8}{10}$ of the length of the vessel,
the deduction is $\frac{75}{100}$ of the allowance for awning deck. Freeboard is $\frac{75}{100}$ of $18\frac{1}{2}$ inches = $13\frac{7}{8}$ inches, and is in proportion to an awning deck 191·2 feet long.

(*c*) $\frac{7}{10}$ of the length of the vessel,
the deduction is $\frac{63}{100}$ of the allowance for awning deck. Freeboard is $\frac{63}{100}$ of $18\frac{1}{2}$ inches = $11\frac{3}{4}$ inches, and is in proportion to an awning deck 183·6 feet long.

(*d*) $\frac{6}{10}$ of the length of the vessel,
the deduction is $\frac{50}{100}$ of the allowance for awning deck. Freeboard is $\frac{50}{100}$ of $18\frac{1}{2}$ inches = $9\frac{1}{4}$ inches, and is in proportion to an awning deck 170 feet long.

These comprising the maximum reductions, it is essential that the erections be of a most substantial character, the deck openings effectually protected, the crew berthed in the bridge house, or with satisfactory arrangements to enable them to get backward and forward to their quarters, and sufficient clearing ports in the bulwarks to speedily clear the deck of water. Vessels of this type having no topgallant forecastle are allowed a less deduction in the amount of freeboard than would otherwise be given for the same length of erections. And if the bridge be a short one, in front of, and only partially covering the engine and boiler openings, again a less deduction is made. No allowance is granted for a monkey forecastle under 4 feet in height, and only when it is of at least the height of the bulwarks.

Note.—A special allowance is made on the freeboard of vessels of the foregoing or *well-decked* type when their erections extend over $\frac{7}{10}$ of their length, when their bridge bulkheads are specially strengthened, and when the area of their water clearing ports in the bulwarks is at least 25 per cent. in excess of the rule requirements. Such additional allowance must not exceed 2 inches.

2. In vessels with topgallant forecastles, short poops, and bridge houses covering engines and boilers in steamers, with efficient iron bulkheads at their ends, when the combined length of erections is—

(*a*) $\frac{5}{10}$ of the length of the vessel,
the deduction is $\frac{2}{5}$ of the allowance for awning deck. Freeboard is $\frac{2}{5}$ of $18\frac{1}{2}$ inches = $7\frac{1}{2}$ inches, and is in proportion to an awning deck 163·2 feet.

(*b*) $\frac{4}{10}$ of the length of the vessel,
the deduction is $\frac{1}{3}$ of the allowance for awning deck. Freeboard is $\frac{1}{3}$ of $18\frac{1}{2}$ inches = $6\frac{1}{4}$ inches, and is in proportion to an awning deck 170 feet (apparently a little out of proportion).

3. In vessels with topgallant forecastles and bridge houses only, covering engines and boilers in steamers, with efficient iron bulkheads at the ends, when the combined length of erections is—

(*a*) $\frac{4}{10}$ of the length of the vessel,
the deduction is $\frac{3}{10}$ of the allowance for awning deck. Freeboard is $\frac{3}{10}$ of $18\frac{1}{2}$ inches $= 5\frac{1}{2}$ inches, and is in proportion to an awning deck 153 feet.
(*b*) $\frac{3}{10}$ of the length of the vessel,
the deduction is $\frac{1}{4}$ of the allowance for awning deck. Freeboard is $\frac{1}{4}$ of $18\frac{1}{2}$ inches $= 4\frac{5}{8}$ inches, and is in proportion to an awning deck 170 feet (apparently a little out of proportion).

The apparent increase in the length of the awning deck in the latter case makes no practical difference in the deduction.

4. In vessels with only topgallant forecastles and poops, the latter with an efficient bulkhead at the fore end, when the combined length of erections is—

(*a*) $\frac{3}{8}$ of the length of the vessel,
the deduction is $\frac{1}{10}$ of the freeboard for the vessel flush decked. Freeboard is $\frac{1}{10}$ of $34\frac{1}{2}$ inches $= 3\frac{1}{2}$ inches, and is in proportion to an awning deck 102·9 feet.
(*b*) $\frac{2}{8}$ of the length of the vessel,
the deduction is $\frac{8}{100}$ of the freeboard for the vessel flush decked. Freeboard is $\frac{8}{100}$ of $34\frac{1}{2}$ inches $= 2\frac{3}{4}$ inches, and is in proportion to an awning deck 121·3 feet.

5. In vessels with topgallant forecastles only, the deduction in freeboard is only one-half in proportion to the previous case (No. 4). Thus, were the erections $\frac{2}{8}$ of the length of the vessel, the deduction would be $\frac{4}{100}$ of freeboard for the vessel flush-decked $= 1\frac{3}{8}$ inches.

6. In vessels with poops only, the allowance is one-half that for the previous paragraph (No. 5) for forecastles only of the same length. Thus, did the length of the poop equal $\frac{2}{8}$ erection, the deduction would be $\frac{2}{100}$ of freeboard for the vessel flush-decked $= \frac{3}{4}$ inch.

7. In vessels with raised quarter decks only, not less than 4 feet high, the deduction is at the same rate as in the preceding paragraph (No. 6).

8. In all vessels when the topgallant forecastle is not closed at the after end by an efficient bulkhead, the length is never to be estimated at a greater full value than $\frac{1}{8}$ of the length of the ship, but any extension beyond this, may be estimated at one-half the value. For example, a vessel 200 feet long has an open forecastle $\frac{1}{4}$ of the length of the ship, or 50 feet; its value for deduction is $25 + 12\frac{1}{2} = 37\frac{1}{2}$ feet. When the topgallant forecastle has an efficient bulkhead with an elongation abaft that bulkhead, the full allowance is given on the entire

length of the closed-in portion, and afterwards according to the previous example.

9. When the poop has no bulkhead, one-half its length is allowed for at the rate of a closed poop.

10. For bridge houses extending from side to side of the vessel, when closed at the fore and open at the after end, with all deck openings, doors, &c., properly protected, $\frac{3}{4}$ of the length is estimated as the value for deduction. When both ends of the alleyways are open, one-half of the length is estimated as the value for deduction.

Note.—Although it is possible to have occasional gales in the summer season as severe as any in winter, yet it is quite unnecessary to remind anyone acquainted with the sea that it is in the latter of these seasons that boisterous weather is looked for. And thus in summer, when the danger from the weather is decreased, there is no reason why a vessel should not be allowed, to some extent, to carry more cargo than in winter. The Board of Trade, therefore, allow a deduction from the winter freeboard for summer voyages, amounting from 1 to 6 or more inches. Summer voyages from European and Mediterranean ports are to be made from April to September inclusive. In other parts of the world, the reduced freeboard should be used during the corresponding or recognised summer months. Vessels, however, engaged in North Atlantic trades, are required to have an addition to their freeboard, varying from 3 to 6 or more inches.

A few examples illustrating how the freeboard is ascertained for different types of vessels may be helpful in showing the practical application of the freeboard rules, &c.

Let it be understood that by Tables A, B, C, and D is meant the freeboard as specified by the Board of Trade for vessels of various types.

Table A.—Flush-decked vessels of the one-, two-, and three-deck type.
Table B.—Spar-decked vessels.
Table C.—Awning-decked vessels.
Table D.—Sailing ships.

Example I.

Flush-decked screw steamer, 300 feet long, 38 feet broad, and 21 feet depth moulded (no account is taken for any erection required for this vessel).

Sheer forward, 8 feet.
Sheer aft, 3 ,,
Coefficient of fineness, 0·8.
Wood deck on upper deck, 4 inches thick.

	Ft.	In
By Table A, for 21 feet depth moulded, the freeboard is . .	4	3
The mean sheer, by rule, for a vessel 300 feet long is $\frac{300}{10} + 10 = 40$ inches. In the example the vessel has 8 feet 0 inches sheer forward, and 3 ,, 0 ,, sheer aft, 2) 11 ,, 0 ,, 5 ,, 6 ,, = 66 inches mean sheer, which is an excess of 66 − 40 = 26 inches (only half of 40* = 20 inches is allowed), therefore, $\frac{20}{4} = 5$ = reduction in freeboard, ...		5
	3	10
The freeboard 4 feet 3 inches from Table A was for a vessel 252 feet long. A correction of 1·2 feet per 10 feet of additional length must now be made and added to the freeboard. 300 − 252 = 48 $\frac{48}{10} \times 1{\cdot}2 = 5{\cdot}76$, about 5¾ inches, . . .		5¾
	4	3¾
If the stringer plate on the deck is, say, ½ inch thick, and the wood deck is 3½ inches above the stringer plate, 4 inches will be deducted, ...		4
	3	11¾
Less for summer, . . .		2½
Summer freeboard measured down from the top of the beam at the side of the vessel at the middle of the length, . .	3	9¼

Example II.

This vessel is identical in every respect with Example I., except that she has a raised quarter deck 4 feet high and 100 feet long, connected with a bridge house 80 feet long, with closed ends, and a topgallant forecastle 30 feet long closed at the after end. The upper deck is iron uncovered with wood.

These erections altogether measure 100 + 80 + 30 = 210 feet.

$$\frac{210}{300} = \frac{7}{10} \text{ erections.}$$

If we turn back to the remarks on *Erections* in this chapter we find that $\frac{7}{10}$ erections are allowed a reduction in the freeboard equal to $\frac{63}{100}$ of the allowance for a complete awning deck.

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* See *Sheer.*

	Ft.	In.
By Table A, the freeboard of the vessel flush decked is . .	4	3
The correction for additional sheer is		6½
	3	8½
By Table C, for a depth of 21 feet, the freeboard is . . .	2	2
(No account is taken of additional sheer in awning-decked vessels).		
The allowance for a complete awning deck is	1	6½

$\frac{63}{100}$ of 1 foot 6½ inches = about 11½ inches = allowance for $\frac{7}{10}$ erections.

Now let us total up all the deductions.

1. Deduction for excess of sheer = ...	6½
2. Deduction for $\frac{7}{10}$ erections = ...	11½
3. Deduction for the thickness of a wood deck when the upper deck is of iron, and covered by $\frac{7}{10}$ or more of substantial erections, ...	4
Deductions, ...	1 10

We have still to make the correction for excess of length.

$\frac{48}{10} \times 1{\cdot}2 = 5{\cdot}76$. But only one-half of this should be taken, since the deck is covered by over $\frac{6}{10}$ erections.

$5{\cdot}76 \div 2 = 2{\cdot}88$ = 2¾ inches to be added to the freeboard, therefore the nett deduction will be 1 foot 10 inches less 2¾ inches = 1 foot 7¼ inches.

	Ft.	In.
The freeboard by Table A is	4	3
The deductions amount to	1	7¼
Winter freeboard, ...	2	7¾
Less for summer, ...		2½
Moulded summer freeboard, ...	2	5¼

Example III.

This vessel has the same dimensions as Example I., with a poop 50 feet long, a bridge house 60 feet long, and a topgallant forecastle 40 feet long.

Iron upper deck uncovered with wood.

Coefficient of fineness = 0·8.

The bridge house is closed at the fore end with an efficient bulkhead, but open at the after end. Three-quarters of its length will, therefore, be reckoned in the erections. ¾ of 60 = 45 feet.

Total erections, 50 + 45 + 40 = 135.

$$\frac{135}{300} = \frac{4}{10} \text{ erections.}$$

The mean sheer at one-eighth the length from each end of the vessel is 40 inches.

	Ft.	in.
By Table A, the freeboard is,	4	3
The mean sheer by the Rule is 30 inches.		
40 − 30 = 10 excess of sheer, $\frac{10}{4} = 2\frac{1}{2}$ reduction in freeboard,		2½
	4	0½
Correction for length (added),		5¾
	4	6¼
By Table C, the freeboard is,	2	2
Correction for length, at the rate of 0·6 foot per 10 feet, is $\frac{48}{10} \times 0{\cdot}6 = 2\frac{3}{4}$ to be added,		2¾
	2	4¾
By Table A, after corrections for sheer and length have been made, the freeboard is,	4	6¼
By Table C, after correction for length only has been made, the freeboard is,	2	4¾
Allowance for complete awning deck =	2	1½
The reduction in freeboard for $\frac{4}{10}$ erections is $\frac{1}{3}$ of the allowance for a complete awning-deck = $\frac{1}{3}$ of 2 feet $1\frac{1}{2}$ inches = $8\frac{1}{2}$ inches.		
By Table A, after the corrections for sheer and length have been made, the freeboard is,	4	6¼
Reduction for $\frac{4}{10}$ erections,		8½
	3	9¾
Reduction for wood deck $\frac{4}{10}$ of $3\frac{1}{2}$ =		1½
Winter freeboard,	3	8¼
Less for summer,		2½
Moulded summer freeboard,	3	5¾

EXAMPLE IV.

Spar-decked steamer 260 feet long, 36 feet broad, and 24 feet depth moulded.

Height of spar deck above main deck, 7 feet.
Spar deck laid with wood deck 4 inches thick.
Coefficient of fineness = 0·8.
Depth moulded to main deck = 17 feet.

	Ft.	in.
By Table B, for 17 feet depth moulded, the freeboard is, . .	6	4½
This is for a length of 288 feet. A correction must be made for decrease in length at 1 inch per 10 feet, and subtracted from the freeboard. 288 − 260 = 28. $\frac{28}{10} \times 1 = 2\cdot8$ = about 2¾ inches, . .		2¾
	6	1¾
Reduction for wood deck, ...		4
Winter freeboard, ...	5	9¾
Reduction for summer, ...		3
Moulded summer freeboard, ...	5	6¾

EXAMPLE V.

Awning-decked vessel 230 feet long, 32 feet broad, and 17 feet depth, moulded to main deck.

Height from main deck to awning deck, 7 feet.
Coefficient of fineness, 0·8.
Mean sheer, 35 inches.
Iron awning deck.

	Ft.	in.
By Table C, for a depth of 17 feet the freeboard is, . . .	1	5½
The mean sheer by the Rule is $\frac{230}{10} + 10 = 33$, and this vessel having sheer in excess of the Rule, no correction is made.		
This freeboard is for a vessel 204 feet long. A correction of 0·5 per 10 feet of additional length must be made, and added to the freeboard. 230 − 204 = 26. $\frac{26}{10} \times 0\cdot5$ = 1¼ inches, . . .		1¼
	1	6¾
Deduction for thickness of wood deck, when awning deck is of iron, ...		3½
Winter freeboard, ...	1	3¼
Less for summer, ...		2½
Moulded summer freeboard (from main-deck beams),	1	0¾

EXAMPLE VI.

Sailing vessel 200 feet long, 34 feet broad, 19 feet deep.
Mean sheer, 40 inches.
Wood deck 3½ inches thick.
Coefficient of fineness, 0·7.

	Ft.	in.
By Table D, for 19 feet depth the freeboard is, ...	3	10
The mean sheer by the Rule is $\frac{200}{10} + 10 = 30$ inches.		
40 − 30 = 10 inches excess of mean sheer.		
$\frac{10}{4} = 2\frac{1}{2}$ inches reduction in freeboard, . .		2½
	3	7½
The length by the Rule for 19 feet depth is 190. A correction must be made at the rate of 1·2 inches per 10 feet excess of length, and added to the freeboard.		
200 − 190 = 10 feet excess of length.		
$\frac{10}{10} \times 1{\cdot}2$ = about 1¼ inches to be added to the freeboard,		1¼
	3	8¾
Less wood deck, ...		3½
Summer freeboard, ...	3	5¼

Note.—Wherever definite rules have been quoted in the chapters on Tonnage and Freeboard, it will be clearly understood that they have been "extracted" from the Board of Trade instructions to surveyors.

TABLE OF NATURAL SINES AND COTANGENTS.

Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.
0	·0000	Infinite.	12	·2079	4·7046	24	·4067	2·2460
¼	·0043	229·1817	12¼	·2121	4·6057	24¼	·4107	2·2199
½	·0087	114·5887	12½	·2164	4·5107	24½	·4146	2·1943
¾	·0130	76·3900	12¾	·2206	4·4193	24¾	·4186	2·1691
1	·0174	57·2899	13	·2249	4·3314	25	·4226	2·1445
1¼	·0218	45·8293	13¼	·2292	4·2468	25¼	·4265	2·1203
1½	·0261	38·1884	13½	·2334	4·1653	25½	·4305	2·0965
1¾	·0305	32·7302	13¾	·2376	4·0866	25¾	·4344	2·0732
2	·0349	28·6362	14	·2419	4·0107	26	·4383	2·0503
2¼	·0392	25·4517	14¼	·2461	3·9375	26¼	·4422	2·0277
2½	·0436	22·9037	14½	·2503	3·8667	26½	·4461	2·0056
2¾	·0479	20·8188	14¾	·2546	3·7982	26¾	·4500	1·9839
3	·0523	19·0811	15	·2588	3·7320	27	·4539	1·9626
3¼	·0566	17·6105	15¼	·2630	3·6679	27¼	·4578	1·9416
3½	·0610	16·3498	15½	·2672	3·6058	27½	·4617	1·9209
3¾	·0654	15·2570	15¾	·2714	3·5457	27¾	·4656	1·9006
4	·0697	14·3006	16	·2756	3·4874	28	·4694	1·8807
4¼	·0741	13·4566	16¼	·2798	3·4308	28¼	·4733	1·8610
4½	·0784	12·7062	16½	·2840	3·3759	28½	·4771	1·8417
4¾	·0828	12·0346	16¾	·2881	3·3226	28¾	·4809	1·8227
5	·0871	11·4300	17	·2923	3·2708	29	·4848	1·8040
5¼	·0915	10·8829	17¼	·2965	3·2205	29¼	·4886	1·7856
5½	·0958	10·3854	17½	·3007	3·1715	29½	·4924	1·7674
5¾	·1001	9·9310	17¾	·3048	3·1239	29¾	·4962	1·7496
6	·1045	9·5143	18	·3090	3·0776	30	·5000	1·7320
6¼	·1088	9·1309	18¼	·3131	3·0325	30¼	·5037	1·7147
6½	·1132	8·7768	18½	·3173	2·9886	30½	·5075	1·6976
6¾	·1175	8·4489	18¾	·3214	2·9459	30¾	·5112	1·6808
7	·1218	8·1443	19	·3255	2·9042	31	·5150	1·6642
7¼	·1261	7·8606	19¼	·3296	2·8635	31¼	·5187	1·6479
7½	·1305	7·5957	19½	·3338	2·8239	31½	·5224	1·6318
7¾	·1348	7·3478	19¾	·3379	2·7852	31¾	·5262	1·6159
8	·1391	7·1153	20	·3420	2·7474	32	·5299	1·6003
8¼	·1434	6·8968	20¼	·3461	2·7106	32¼	·5336	1·5849
8½	·1478	6·6911	20½	·3502	2·6746	32½	·5373	1·5696
8¾	·1521	6·4971	20¾	·3542	2·6394	32¾	·5409	1·5546
9	·1564	6·3137	21	·3583	2·6050	33	·5446	1·5398
9¼	·1607	6·1402	21¼	·3624	2·5714	33¼	·5482	1·5252
9½	·1650	5·9757	21½	·3665	2·5386	33½	·5519	1·5108
9¾	·1693	5·8196	21¾	·3705	2·5065	33¾	·5555	1·4966
10	·1736	5·6712	22	·3746	2·4750	34	·5591	1·4825
10¼	·1779	5·5300	22¼	·3786	2·4443	34¼	·5628	1·4686
10½	·1822	5·3955	22½	·3826	2·4142	34½	·5664	1·4550
10¾	·1865	5·2671	22¾	·3867	2·3847	34¾	·5699	1·4414
11	·1908	5·1445	23	·3907	2·3558	35	·5735	1·4281
11¼	·1950	5·0273	23¼	·3947	2·3275	35¼	·5771	1·4149
11½	·1993	4·9151	23½	·3987	2·2998	35½	·5807	1·4019
11¾	·2036	4·8076	23¾	·4027	2·2726	35¾	·5842	1·3890

TABLE OF NATURAL SINES AND COTANGENTS (*continued*).

Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.
36	·5877	1·3763	48	·7431	·9004	60	·8660	·5773
36¼	·5913	1·3638	48¼	·7460	·8925	60¼	·8681	·5715
36½	·5948	1·3514	48½	·7489	·8847	60½	·8703	·5657
36¾	·5983	1·3391	48¾	·7518	·8769	60¾	·8724	·5600
37	·6018	1·3270	49	·7547	·8692	61	·8746	·5543
37¼	·6052	1·3150	49¼	·7575	·8616	61¼	·8767	·5486
37½	·6087	1·3032	49½	·7604	·8540	61½	·8788	·5429
37¾	·6122	1·2915	49¾	·7632	·8465	61¾	·8808	·5373
38	·6156	1·2799	50	·7660	·8391	62	·8829	·5317
38¼	·6190	1·2684	50¼	·7688	·8316	62¼	·8849	·5261
38½	·6225	1·2571	50½	·7716	·8243	62½	·8870	·5205
38¾	·6259	1·2459	50¾	·7743	·8170	62¾	·8890	·5150
39	·6293	1·2348	51	·7771	·8097	63	·8910	·5095
39¼	·6327	1·2239	51¼	·7798	·8025	63¼	·8929	·5040
39½	·6360	1·2130	51½	·7826	·7954	63½	·8949	·4985
39¾	·6394	1·2023	51¾	·7853	·7883	63¾	·8968	·4931
40	·6427	1·1917	52	·7880	·7812	64	·8987	·4877
40¼	·6461	1·1812	52¼	·7906	·7742	64¼	·9006	·4823
40½	·6494	1·1708	52½	·7933	·7673	64½	·9025	·4769
40¾	·6527	1·1605	52¾	·7960	·7604	64¾	·9044	·4716
41	·6560	1·1503	53	·7986	·7535	65	·9063	·4663
41¼	·6593	1·1402	53¼	·8012	·7467	65¼	·9081	·4610
41½	·6626	1·1302	53½	·8038	·7399	65½	·9099	·4557
41¾	·6658	1·1204	53¾	·8064	·7332	65¾	·9117	·4504
42	·6691	1·1106	54	·8090	·7265	66	·9135	·4452
42¼	·6723	1·1009	54¼	·8115	·7198	66¼	·9153	·4400
42½	·6755	1·0913	54½	·8141	·7132	66½	·9170	·4348
42¾	·6788	1·0817	54¾	·8166	·7067	66¾	·9187	·4296
43	·6819	1·0723	55	·8191	·7002	67	·9205	·4244
43¼	·6851	1·0630	55¼	·8216	·6937	67¼	·9222	·4193
43½	·6883	1·0537	55½	·8241	·6872	67½	·9238	·4142
43¾	·6915	1·0446	55¾	·8265	·6808	67¾	·9255	·4091
44	·6946	1·0355	56	·8290	·6745	68	·9271	·4040
44¼	·6977	1·0265	56¼	·8314	·6681	68¼	·9288	·3989
44½	·7009	1·0176	56½	·8338	·6618	68½	·9304	·3939
44¾	·7040	1·0087	56¾	·8362	·6556	68¾	·9320	·3888
45	·7071	1·0000	57	·8386	·6494	69	·9335	·3838
45¼	·7101	·9913	57¼	·8410	·6432	69¼	·9351	·3788
45½	·7132	·9826	57½	·8433	·6370	69½	·9366	·3738
45¾	·7163	·9741	57¾	·8457	·6309	66¾	·9381	·3689
46	·7193	·9656	58	·8480	·6248	70	·9396	·3639
46¼	·7223	·9572	58¼	·8503	·6188	70¼	·9411	·3590
46½	·7253	·9489	58½	·8526	·6128	70½	·9426	·3541
46¾	·7283	·9407	58¾	·8549	·6068	70¾	·9440	·3492
47	·7313	·9325	59	·8571	·6008	71	·9455	·3443
47¼	·7343	·9243	59¼	·8594	·5949	71¼	·9469	·3394
47½	·7372	·9163	59½	·8616	·5890	71½	·9483	·3345
47¾	·7402	·9083	59¾	·8638	·5831	71¾	·9496	·3297

TABLE OF NATURAL SINES AND COTANGENTS (*continued*).

Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.	Degree.	Sine.	Cotangent.
72	·9510	·3249	78¼	·9790	·2080	84½	·9953	·0962
72¼	·9523	·3201	78½	·9799	·2034	84¾	·9958	·0918
72½	·9537	·3152	78¾	·9807	·1989	85	·9961	·0874
72¾	·9550	·3105	79	·9816	·1943	85¼	·9965	·0830
73	·9563	·3057	79¼	·9824	·1898	85½	·9969	·0787
73¼	·9575	·3009	79½	·9832	·1853	85¾	·9972	·0743
73½	·9588	·2962	79¾	·9840	·1808	86	·9975	·0699
73¾	·9600	·2914	80	·9848	·1763	86¼	·9978	·0655
74	·9612	·2867	80¼	·9855	·1718	86½	·9981	·0611
74¼	·9624	·2820	80½	·9862	·1673	86¾	·9983	·0567
74½	·9636	·2773	80¾	·9869	·1628	87	·9986	·0524
74¾	·9647	·2726	81	·9876	·1583	87¼	·9988	·0480
75	·9659	·2679	81¼	·9883	·1539	87½	·9990	·0436
75¼	·9670	·2632	81½	·9890	·1494	87¾	·9992	·0392
75½	·9681	·2586	81¾	·9896	·1449	88	·9993	·0349
75¾	9692	·2539	82	·9902	·1405	88¼	·9995	·0305
76	·9702	·2493	82¼	·9908	·1360	88½	·9996	·0261
76¼	·9713	·2446	82½	·9914	·1316	88¾	·9997	·0218
76½	·9723	·2400	82¾	·9920	·1272	89	·9998	·0174
76¾	·9733	·2354	83	·9925	·1227	89¼	·9999	·0130
77	·9743	·2308	83¼	·9930	·1183	89½	·9999	·0087
77¼	·9753	·2262	83½	·9935	·1139	89¾	·9999	·0043
77½	·9762	·2216	83¾	·9940	·1095	90	1·0000	·0000
77¾	·9772	·2171	84	·9945	·1051			
78	·9781	·2125	84¼	·9949	·1006			

APPENDIX A.

The Author desires, in conclusion, to call the attention of such of his readers as have some mathematical attainments to an able Paper, read before the Institute of Marine Engineers, on Jan. 12, 1892, by Mr. John A. Rowe, Surveyor to the Board of Trade. From this Paper, which was kindly placed at his disposal, he has made the following extract, which will be found of much interest :—

DYNAMIC STABILITY AND OSCILLATIONS AMONG WAVES.

"Most of you are aware that in computing the rolling period of a ship—that is, the time in seconds she will take to roll from the vertical and back again—she is somehow or other regarded as a pendulum. This is a correct view to take of the matter if the subject is approached in a proper direction. But many able men have been perplexed by what has appeared to be the contradiction between theory and practice. For instance, most of you are aware that the period T of a bob-pendulum in seconds is :

$$T = 3{\cdot}1416 \times \sqrt{\frac{\text{Length in feet}}{\text{Gravity}}} = 3{\cdot}1416 \times \sqrt{\frac{R}{32}} = {\cdot}554 \times \sqrt{R}$$

R is the length of the pendulum in feet.

In this formula it is clear that the period of a pendulum varies as the square root of its length.

For the smooth water period of a ship the formula is somewhat different, and is as follows :—

$$T = 3{\cdot}1416 \sqrt{\frac{\text{Radius of Gyration squared}}{\text{Gravity} \times \text{Metacentric Height}}} = {\cdot}554 \times \sqrt{\frac{R^2}{G\,M}}$$

The radius of gyration and the metacentric height to be in feet.

An examination of this formula reveals the fact that a vessel's rolling period varies directly as the radius of gyration, and inversely as the square root of the metacentric height. If G M be increased in length, the vessel's period will be shortened, and she will become a quicker roller than before. But practical men, looking at the usual diagrams, have reasoned thus :—'The length G M is the distance between the vessel's point of oscillation and her centre of gravity. If there is any pendulum-like motion in the ship it is of necessity about G or M, at a length G M.'

But the formula $T = {\cdot}554 \times \sqrt{\frac{R^2}{G\,M}}$ shows clearly enough, as does also the formula for a simple pendulum, that R is the pendulum length and and G M is something entirely different. The following Fig. has been constructed by the writer in the hope of simplifying some points not generally understood.

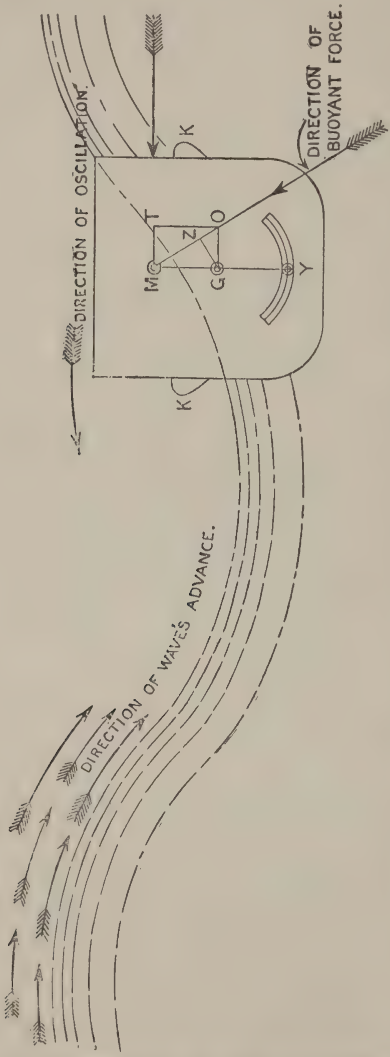
DIRECTION OF OSCILLATION.
DIRECTION OF BUOYANT FORCE.
K
T
O
Z
M
G
Y
K
DIRECTION OF WAVE'S ADVANCE.

Fig. 118.—Diagram to illustrate the dynamic stability stored in an upright vessel through a change of the direction of the force of buoyancy from the vertical to the direction O M at right angles to the wave-slope.

The vessel is shown upright on the wave-slope. In this position the force of buoyancy, *which acts at right angles to the wave surface*, as it acts at right angles to the surface of smooth water, creates a righting arm G Z. This length in feet, multiplied by the ship's weight in tons, is what we have called the vessel's righting moment in foot-tons. In the position we have shown her, it is obvious that this power, usually regarded as the power of recovery, starts the vessel rolling; and if, after she had acquired a position at right angles to the wave-slope, we could instantly give a smooth surface to the sea she would roll through the angle G M O on each side of the vertical, and gradually extinguish the range of oscillation by the fluid resistance offered to the immersed portion of the hull.

Again, if G O and M T be drawn at right angles to G M, and T O drawn parallel to G M, we obtain a parallelogram of forces, whose resultant M O may be regarded as the buoyant force which equals the weight of the ship, and whose components are G M and M T. As G M is acting upward through the vessel's centre line we may disregard it, and direct our attention exclusively to the component M T, whose direction is shown by arrow, and whose amount is M O × sine of the angle of inclination.

Let the effective angle of the wave-slope be 9°, the vessel's weight 10,000, her metacentric height 6 feet. Find the turning moment about G, the vessel's centre of gravity.

The component M T = M O × sine of 9° = 10,000 tons × ·156 = 1,560 tons.

This force of 1,560 acts at the end of the lever G M = 6 feet; therefore, the righting, or in this case, the turning moment

= 1,560 tons × 6 feet = 9,360 foot-tons.

But the righting moment is the weight of the ship multiplied by the righting arm. What is the product of these quantities?

$$\text{G Z, the righting arm} = \text{G M} \times \text{sine of } 9^\circ = \overset{\text{Ft.}}{6} \times \cdot156 = \overset{\text{Foot.}}{\cdot936}.$$

$$\text{Righting moment} = \overset{\text{Tons.}}{10{,}000} \times \overset{\text{Foot.}}{\cdot936} = 9{,}360 \text{ foot-tons.}$$

Both calculations declare the righting moment to be 9,360 foot-tons.

In other words, the weight of the ship into the righting arm G Z = the component M T into the metacentric height. If now we plot Y as the centre of gyration, we shall be able to realize the nature of the force tending to produce motion, and the character of the resistance offered to it.

Let us for a moment suppose that G is a fixed point—the ship's fulcrum. Let us also regard the ship as a portion of a huge wheel (a portion of a fly-wheel) its radius of gyration being G Y.

By an examination of the Fig. it will be seen that the greater G M is (with a given horizontal force M T) the greater is the turning moment. And the smaller the radius of gyration G Y, the smaller will be the resistance and the quicker will be the motion of oscillation. The forces necessary to produce and maintain oscillations in a heavy and in a light boat respectively, will help to an understanding of this problem. The moment of the accelerating forces about the centre of suspension varies as the weight of the boat.

To obtain great stability and quick motion, we must increase the leverage G M, and reduce the pendulum length G Y; to obtain moderate stability, but a slow angular motion, and, therefore, a comfortable vessel at sea, and one offering a steady gun-platform, we must diminish the leverage G M and increase the length of G Y.

With regard to G Y, which is obtained by dividing the vessel's moment of inertia about G by the sum of the weights, and extracting the square root, it is evident that it can be of great length only in a large vessel. In a small vessel, G Y can be increased by placing movable weights towards the bulwarks, but no such change as this will be sufficient to make the radius of gyration great enough to give rise to a slow rate of oscillation. An easy motion in small crafts may be obtained by shortening GM, but this may give rise to want of stability. Hence the difficulty of builders to make a perfect ship. They have to steer between Scylla and Charybdis. Worse still, they strive to please shipowners, who know but little of the difficulties of naval architecture; and to please themselves, with the result that they sometimes please neither. . . .

Wave action upon ships, stores wave energy *in* ships to an extent depending on their weight and length of righting arm; and the manner of ascertaining the amount of work put into a ship is as follows:—The force M T = 1,560 tons, becomes nil when the vessel's deck is parallel to the wave-slope or to a smooth sea. Therefore the *mean* force acting to turn the ship at M about the centre G is $\frac{M\,T}{2} = \frac{1{,}560}{2} = 780$ tons. This *mean* force acts through the space M T = M G × tangent of the angle of inclination = 6 feet × ·158 = ·948 foot. And 780 tons × ·948 foot = 739·44 foot-tons dynamical stability. . . .

Storm-waves produce violent rolling in the largest of floating structures, and these structures are occasionally brought to rest by a sudden and complete expenditure of their stored energy. And the greater the energy *in* the vessel—*i.e.*, the heavier the *ship*, and the quicker the motion, the more tremendous is the blow she can inflict upon an approaching wave. But, unhappily, when the momentum of an ocean wave is not only resisted by a vessel's hull, but is increased by the dynamic energy of the ship, a climax occurs, the severity of the blow is manifested by the vessel ceasing to roll (her energy being expended), and by the wave bursting high above the decks and sweeping them from end to end. This condition of things as about to happen, the writer wishes to convey in the rough sketch by arrows, showing the direction of the ship's oscillation and the wave's advance. The Fig. is not by any means to scale." The projections K K on each side of the diagram are short lengths of troughs which, in Mr. Rowe's opinion, would prevent rolling. They are open ended, and the dimensions would vary with the weight of the ship and the metacentric height. They would probably render torpedo boats habitable in choppy seas and stormy weather.—(From paper on "Stability and Motions of a Vessel among Waves," by John A Rowe. Part ii., p. 10, *et seq.*).

APPENDIX B.

TEST QUESTIONS.*

CHAPTER I.

1. What is displacement? What is a displacement curve? Explain its construction and use.

2. What is deadweight? What is a deadweight scale, and how is it constructed?

3. What is meant by "tons per inch" immersion? Give and explain the rule for "tons per inch" immersion.

4. Explain how a curve of "tons per inch" immersion is constructed, and show clearly its use.

5. What is a coefficient of displacement? State approximately the coefficient for an average cargo steamer, and a fine passenger steamer.

6. What is the weight of 1 cubic foot of salt water and 1 cubic foot of fresh water? How many cubic feet of salt water, and also fresh water, are there in 1 ton?

7. Find the displacement of a box ship floating light in sea water at a draught of 5 feet forward and 6 feet aft. The length is 100 feet; the breadth 20 feet (use mean draught). *Ans.* 314·2 tons.

8. When loaded, the box ship in the previous question draws 12 feet of water fore and aft. What is the deadweight? *Ans.* 371·5 tons.

9. A ship of 1000 tons displacement, loaded, is floating in sea water. What will be the change in draught in passing into river water? The "tons per inch" at the load line is 9. *Ans.* Draught increases 1·7 inches.

10. A steamer on a voyage burns 200 tons of coal. The "tons per inch" is 24. What is the approximate change in draught? *Ans.* Draught decreases 8·3 inches.

11 A vessel is 200 feet long, 30 feet broad, and of 16 feet depth to top of weather deck at amidships. The freeboard is, say, 2 feet, and the coefficient of fineness ·65. What is her displacement in salt water? *Ans.* 1560 tons.

CHAPTER II.

12. What is meant by saying that a vessel has a righting or a capsizing moment?

13. Define the term centre of gravity.

14. A ship has a displacement of 2000 tons when floating at a certain draught; 100 tons are then placed on deck at a height of 9 feet above the centre of gravity of the ship as it was before the weight was placed on board. Find the alteration in the position of the centre of gravity. *Ans.* Centre of gravity is raised ·42 foot.

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* Many of these questions are taken from Science and Art Examination Papers.

15. A ship, with a displacement of 2000 tons, has a weight of 100 tons already on board on the centre of the upper deck, moved 8 feet to the port side. Find the distance the centre of gravity has shifted. *Ans.* ·4 foot.

16. The centre of gravity of a ship is 12 feet from the bottom of the keel. In this condition her displacement is 2500 tons. She is then loaded in the following manner :—100 tons are placed 9 feet above the bottom of the keel, 300 tons 14 feet, and 500 tons 12 feet. Find the new position of the centre of gravity from the bottom of the keel. *Ans.* 12·08 feet.

CHAPTER III.

17. What is meant by buoyancy, reserve buoyancy, centre of buoyancy?

18. How do water pressures act? Which of them afford support?

19. What is meant by sheer? and explain its use.

20. Of what value are deck erections as regards buoyancy?

21. What is the vertical centre of buoyancy? also longitudinal centre of buoyancy?

22. Show how curves of longitudinal and vertical centres of buoyancy are constructed.

23. Supposing a ship's longitudinal centres of buoyancy to be in the middle of the length at every draught when floating on even keel, and she is loaded in the following manner :—

10 tons are placed 30 feet forward of the centre of buoyancy
120 ,, 50 ,, ,, ,,
500 ,, 60 ,, ,, ,,
400 ,, 70 feet aft ,, ,,
15 ,, 60 ,, ,, ,,
150 ,, 25 ,, ,, ,,

Where would a weight of 200 tons need to be placed on board to bring her again on even keel? *Ans.* 18·25 feet aft of the centre of buoyancy.

24. Why does a ship increase in draught on a comparatively small compartment being damaged below the water level, into which the sea enters?

25. What is meant by camber, and why is it given to a vessel? State the rule for the minimum.

26. A box ship is 100 feet long, 20 feet broad, and floats at 6 feet draught. Calculate the amount of upward water pressure in lbs. *Ans.* 768,000 lbs.

CHAPTER IV.

27. Enumerate in order of importance the principal strains to which a ship may be subject.

28. State clearly what strains a ship may experience when floating light and in calm water.

29. Show how strains may be decreased or enormously increased in the operation of loading.

30. Describe the strains experienced by a ship among waves—fore and aft and athwartships.

31. Explain the term "unequal distribution of weight and buoyancy."

32. What is a compressive strain and a tensile strain?

33. Show in any graphic way how to combine and arrange the material used in the construction of ships to give greatest resistance to bending.

34. What kind of ships offer greatest resistance to longitudinal bending, and which offer least?

35. Where are the fore and after strains greatest? Show why.

36. What is the tendency of strains due to rolling motion?

37. What strains are supposed to be provided for in vessels built to the requirements of the recognized classifying societies? What strains may a vessel experience which such rules do not profess to cover?

CHAPTER V.

38. Enumerate the parts of a ship's structure known as transverse framing. What is the function of transverse framing?

39. Describe carefully and in detail how the parts which make up a complete transverse frame are connected with one another, and also the various forms of material which may be used.

40. What is meant by compensation in ship construction? Give illustrations.

41. Give rules for beam knees.

42. Which are the best beams to fit under iron or steel decks, and also under wooden decks? Give illustrations.

43. What depth must a ship be to require two tiers of beams, and also three tiers of beams?

44. How may the lowest of these tiers be dispensed with, and state clearly the compensation made for the loss?

45. What are web frames? When and where are they fitted?

46. State which parts of the transverse framing specially resist the tendency to "working," produced by rolling motion.

47. Mention the parts comprising longitudinal framing. What is the function of longitudinal framing?

48. What means are adopted to secure a good connection between the longitudinal and the transverse framing?

49. What is a bar keel? How are the parts comprising this keel connected?

50. What is a keelson and a stringer?

51. Sketch roughly the different forms of keels and centre keelsons, and state which (if any) combination is preferable.

52. What is the garboard strake? The sheer strake?

53. How is it that most of the material used in a ship's construction is reduced in thickness towards the ends?

54. Describe any method adopted to compensate for cutting down a centre keelson or reducing a stringer plate in width.

55. Describe what provision may be made to resist panting strains, and also strains from masts due to wind pressure.

56. What are the special characteristics of a three-deck, a spar-decked, an awning-decked, and a quarter-deck vessel?

57. Why are bulkheads fitted? Show how they are connected to the shell plating. To what height are bulkheads carried? How is a recessed bulkhead made watertight?

58. Show how a bulkhead is made watertight where a keelson or stringer passes through it.

59. What is a rimer and a drift punch, and their use? Which is the best form of rivet, and why?

CHAPTER VI.

60. Define the term "stability."

61. What are the two factors producing moment of stability?

62. What is the metacentre? What is metacentric height?

63. What is meant by a righting moment of stability?

64. State the conditions under which a vessel will float in stable equilibrium.

65. What is the condition of a ship which is said to be "stiff" or "tender?"

66. Having given the metacentric height, how can the righting lever be found, and when is it unsafe to adopt this method?

67. Give the formula for finding the height of the metacentre above the centre of buoyancy.

68. What features in the design are most important in influencing the height of metacentre?

69. How can stiffness be obtained?

70. What is a curve of stability, and how is it constructed?

71. It is usual for the metacentre to fall when the draught is increasing from light towards the load draught, but on approaching the load it is often found to rise again. What explanation can be given for this?

72. Describe clearly the steps of the operation for finding the metacentric height by experiment.

73. Describe clearly the effect of beam, freeboard, and height of centre of gravity upon the maximum levers and range of stability.

74. What is tumble home?

75. State the relation between metacentric height and transverse rolling motions in still water.

76 Enumerate the resistances to rolling motions.

77. What are bilge keels, and why are they fitted? What is the danger among waves of great metacentric height?

78. What methods may be adopted to obtain steadiness among waves, and state clearly the condition of a vessel effected by each of these methods?

79. What is meant by synchronism? How is it produced and how averted? What conditions of loading are most liable to produce it?

80. State how it is that similar metacentric heights for load and light or ballast conditions do not produce similar stability and behaviour at sea.

81. What are the most important considerations in ballasting as regards the amount, position, and securing the ballast?

82. What is the condition and danger developed by a shifted cargo?

83. What means may be adopted to prevent a cargo shifting?

84. State under what conditions a vessel's behaviour and stability may vary upon a single voyage.

85. State under what circumstances a ship will sink or capsize, owing to the entry of water into the interior, either through an opening in the deck or a hole in the side or bottom below the water level.

86. What are the necessary features or conditions of a vessel in order to be able to carry large sail area?

87. Enumerate the chief resistances to propulsion.

CHAPTER VII.

88. What is meant by gross and underdeck tonnage, and what spaces are ncluded in each?

89. Enumerate the deductions from the gross tonnage for register tonnage.

90. How is the propelling space deduction in steamers obtained?

91. When are deep water-ballast tanks allowed as deductions, and when are they not?

92. How are deck cargoes reckoned as regards tonnage?

93. What are the important differences between the ordinary tonnage and Suez Canal tonnage?

CHAPTER VIII.

94. What is meant by the term "freeboard?"

95. What are the leading considerations in determining the freeboard for any particular vessel?

96. Why have spar-decked vessels more freeboard than three-deckers, and awning than spar-deckers?

97. What effect have sheer, camber, length, and deck erections upon freeboard?

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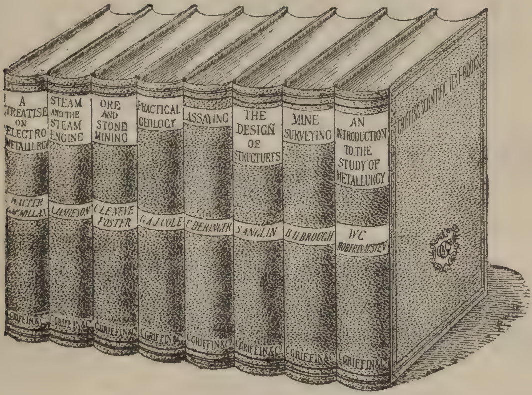

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